INFORMATION TO USERS

This material was produced from a microfilm copy of the original document. While the most advanced technological means to photograph and reproduce this document have been used, the quality is heavily dependent upon the quality of the original submitted.

The following explanation of techniques is provided to help you understand markings or patterns which may appear on this reproduction.

1. The sign or "target" for pages apparently lacking from the document photographed is "Missing Page(s)". If it was possible to obtain the missing page(s) or section, they are spliced into the film along with adjacent pages. This may have necessitated cutting thru an image and duplicating adjacent pages to insure you complete continuity.

2. When an image on the film is obliterated with a large round black mark, it is an indication that the photographer suspected that the copy may have moved during exposure and thus cause a blurred image. You will find a good image of the page in the adjacent frame.

3. When a map, drawing or chart, etc., was part of the material being photographed the photographer followed a definite method in "sectioning" the material. It is customary to begin photoing at the upper left hand corner of a large sheet and to continue photoing from left to right in equal sections with a small overlap. If necessary, sectioning is continued again — beginning below the first row and continuing on until complete.

4. The majority of users indicate that the textual content is of greatest value, however, a somewhat higher quality reproduction could be made from "photographs" if essential to the understanding of the dissertation. Silver prints of "photographs" may be ordered at additional charge by writing the Order Department, giving the catalog number, title, author and specific pages you wish reproduced.

5. PLEASE NOTE: Some pages may have indistinct print. Filmed as received.

Xerox University Microfilms
300 North Zeeb Road
Ann Arbor, Michigan 48106

76-6510

CRIPPEN, Loretta Kaye, 1945-
MOISTURE TRANSPORT PROPERTIES OF SELECTED
KNIT FABRICS.

The University of North Carolina at Greensboro,
Ph.D., 1975
Home Economics

Xerox University Microfilms, Ann Arbor, Michigan 48106

MOISTURE TRANSPORT PROPERTIES OF SELECTED KNIT FABRICS

by

Loretta Kaye Crippen

A Dissertation Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
1975

Approved by

Victor S. Salvin
Dissertation Adviser

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Dissertation Adviser Victor S. Salvia

Committee Members Pauline E. Keeney

Mildred B. Johnson

Eunice M. Deemer

Sigrid A. Trombley

March 24, 1975

Date of Acceptance by Committee

CRIPPEN, LORETTA KAYE. Moisture Transport Properties of Selected Knit Fabrics. (1975). Directed by Dr. Victor Salvin. Pp. 291.

The purpose of this research was to examine the role of fiber content and fabric structure on the moisture transport properties of selected knit fabrics. Moisture transport is an important factor in clothing comfort as related to evaporative cooling. Test fabrics included jersey and interlock weft knit structures in 100 percent cotton, 100 percent polyester, and 50/50 percent cotton/ polyester. The knits represented double and single knit structures and hydrophobic, hydrophilic, and blended fibers.

No standard moisture transport test methods have been adopted for apparel fabrics. Most tests used previously measured only vapor transport in ambient air currents. A series of four moisture transport tests were developed to more fully replicate use conditions which included vapor and liquid transport with and without moderate air currents over the upper surface of the fabric.

The volumetric test method developed used a water filled vessel attached to a capillary tube. The amount and rate of moisture transport were determined. The vapor tests were performed with the fabric 1.5 cm from the moisture surface. A wicking polyurethane sponge, in contact with the water supply and test fabric, was used for the liquid test method. Differences in data were due to

variations in experimental procedure and variations in knit structure and finishing.

The moisture transport test series examined two fabric variables, fiber content and fabric structure, and two treatment variables, air velocity and moisture form. Four-way analysis of variance suggested that the following main effects were statistically significant at the .05 level: fiber content, fabric structure, and air velocity.

Newman-Keuls' statistical analysis suggested that moisture transport rate for 50/50 percent cotton/polyester, the fastest transporter, did not significantly differ from 100 percent polyester. However, the 50/50 percent cotton/polyester and the 100 percent polyester differed significantly from 100 percent cotton, the slowest transporter.

The interlock knit structures transported significantly more moisture than the jersey knit structures. The use of moderate air currents over the upper surface of the fabric resulted in a significant increase in moisture transport over the use of ambient air.

The following interaction effects were suggested to be significant at the .05 level: fabric structure/air velocity, fiber content/moisture form, fiber content/air velocity, fabric structure/fiber content/moisture form, fabric structure/fiber content/air velocity, and fiber content/moisture form/air velocity. No significant first-order interaction effect was suggested between fiber content and fabric structure.

Spearman rho rank order correlation was used to determine whether a relationship existed between the following: (1) various tests in the moisture transport test series, (2) tests in the moisture transport test series and basic fabric property tests such as vertical wicking which are frequently used as indicators of moisture transport, and (3) various basic fabric properties.

No correlations were statistically significant between the various tests in the moisture transport test series which used either the same moisture form or air velocity. Not all the tests in the moisture transport series suggested a correlation with a basic fabric property. Use of the four tests in the moisture transport test series was recommended to more fully replicate use conditions.

Additional research to examine moisture transport as related to physiological clothing comfort is needed. A standard test method which replicates various use conditions should be adopted for industry use.

ACKNOWLEDGEMENTS

The author wishes to thank everyone who offered technical assistance and encouragement during this research project.

Special appreciation is expressed to Dr. Victor Salvin who directed the dissertation. Other committee members who offered assistance included Dr. Eunice Deemer, Dr. Mildred Johnson, Dr. Pauline Keeney, Dr. Sigrid Trombley, and the late Dr. Frances Buchanan.

Thanks is expressed to Dr. Richard Resurreccion who prepared the diagrams. Appreciation is expressed to everyone who aided with the statistical and computer analyses. Gratitude is expressed to the textile companies that donated test fabrics for this research.

Additional thanks are expressed to the faculty at California State University at Los Angeles, family, and friends for their encouragement.

TABLE OF CONTENTS

Page

Chapter Page

APPENDIXES Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Chapter 1

INTRODUCTION

Clothing, man, and the environment function as a system to maintain body temperature and thermal comfort. The basic thermal principle for maintenance of body temperatures is that heat taken into the body must equal the heat given off by the body. Heat exchange is achieved by conduction, convection, radiation, and evaporation of moisture.

The consumer and producer of textiles should be aware of comfort aspects of clothing. The ability of a fabric to efficiently transport both vapor and liquid moisture from the skin's surface to the outer environment for evaporation is a major thermal comfort factor. This research was limited to the examination of physiological aspects of thermal comfort as related to moisture transport properties of knit apparel fabrics.

The body constantly gives off heat in the form of water vapor which is termed insensible perspiration. Under normal conditions, evaporation from the skin's surface accounts for about 25 percent of the total heat loss from the body (1,2). With increases in activity level and/or environmental conditions, perspiration becomes liquid which is termed sensible perspiration or sweat. Dependence upon evaporation of sweat for maintenance of body temperature increases greatly during more severe conditions. The cooling effect which occurs during the evaporation of sweat results from the latent heat of vaporization.

Evaporation of perspiration from the skin's surface is altered by clothing; therefore, it is said that clothing acts as a barrier to the evaporation of perspiration (3). Moisture is transported from the skin; through the fiber, fabric, and/or garment openings; and to the outer environment for evaporation.

Several problems are associated with insufficient moisture transport away from the skin. If vapor or insensible perspiration is not quickly removed from the skin's surface, the relative humidity increases between the skin and fabric. This condensation of moisture is associated with discomfort known as a "clammy" feeling. When excess liquid collects on the skin, it can drip or run down the body. The evaporative cooling effect is not obtained when evaporation cannot occur. In severe cases, heat stress occurs when heat production exceeds heat loss.

Renbourn (4) suggested that clothing comfort is a neutral state with the two opposite poles being pleasure and pain. Kemp (5) suggested that the consumer is concerned only with clothing comfort after experiencing discomfort. Discomfort is perhaps more likely to occur during increased activity level and/or environmental conditions.

Much comfort research has been done at the Army Natick Laboratory to develop military clothing systems. However, military research findings have not been used to produce more comfortable ready-to-wear apparel. Textile companies have done little comfort research. However, it is predicted that as ease-of-care and aesthetic properties become assured, the textile and apparel industries will be more concerned with the comfort factor. More research is needed to determine the relationship and importance of fabric variables in producing comfortable apparel. Research findings should be transmitted in understandable terms to textile and apparel designers.

Two important fabric variables are fiber content and fabric structure. Confusion still exists concerning the role of fiber content in producing fabric which allows sufficient moisture transport. The question of which fiber to use, a hydrophobic or a hydrophilic one, appears unsettled. Special interest fiber groups promote their fibers as being the most comfortable. A recent cotton advertisement (6) promoted the comfort of cotton by promoting the superior absorbency of cotton over synthetic fibers. The advertisement used the slogan, "the more cotton, the more comfort." Often claims are supported by laboratory research; however, the results are often indicative of the test methods and procedures used.

The role of fabric structure in moisture transport has been examined mainly in relation to woven fabrics. Little research has been performed to examine moisture transport properties of various knit structures. Knight et al. (7,8) determined that significant differences existed in the moisture transport abilities of two single weft knit structures; the rate of vapor transport was significantly faster for the jersey knits than for the rib knits. No research has compared transport rates of single and double knit structures.

Most research has measured only vapor transport. A test method which could determine both vapor and liquid transport using the same basic apparatus would be ideal. Confusion still exists concerning what to measure, how to measure it, and what units to use to describe moisture transport properties of fabrics (9). No standard test method has been established for apparel fabrics in the United States. Canada has a standard test method for vapor transport (10). A test method capable of measuring both vapor and liquid transport is needed.

STATEMENT OF THE PROBLEM

The major purpose of this research was to examine moisture transport properties of selected knit fabric to determine the role of fiber content and fabric structure in producing a fabric with acceptable moisture transport properties. Since no standard test method existed, it was necessary to develop a method to measure both vapor and liquid transport with ambient air and moderate air currents over the upper surface of the fabric. The environmental conditions used in this research simulated those of a hot, dry environment.

The specific objectives of this research were:

1. To design test apparatus and to develop test procedures to measure moisture transport properties of knit apparel fabrics. The tests will measure vapor and liquid transport with and without convection currents.

2. To measure the moisture transport rate of plain weft jersey and interlock knit structures of 100 percent cotton, 100 percent polyester, and 50/50 percent cotton/polyester to determine:

   a. whether differences exist in moisture transport of knits made from 100 percent cotton, 100 percent polyester, and 50/50 percent cotton/polyester in order to examine the role of a hydrophilic and a hydrophobic fiber in moisture transport;

b. whether differences exist in moisture transport of plain weft jersey and interlock knit structures in order to examine the role of fabric structure in moisture transport;

c. the importance of fiber content and/or fabric structure in determining the rate of moisture transport;

d. the rate of vapor transport and liquid transport; and

e. the role of convection currents on moisture transport through selected knits.

3. To determine whether a relationship exists between the researcher developed moisture transport tests and other tests frequently used as indicators of moisture transport.

DEFINITIONS OF TERMS

The following definitions were used in this research:

Air Permeability. The rate of air flow through a material under a differential pressure between the two fabric surfaces (11).

Course. The row of loops running crosswise in knitted fabrics corresponds to the weft in a woven fabric (12).

Double Knit. Refers to any of the numerous kinds of fine rib structures that have the appearance of twice knitted jersey fabric. Double knit fabric by reason of its two-needle construction is a more dimensionally stable cloth than single needle or conventional jersey fabric. It also tends to be a heavier piece of fabric (12).

Fabric, Knitted. A structure produced by interlooping one or more ends of yarn or comparable material (11).

Interlock Knitting. A method of rib knitting on a circular machine with alternate long and short needles in cylinder and dial. In operation, the alternate needles knit and welt at alternate feeds. Thus, each full course of the fabric requires the use of two consecutive feeds, each feed knitting a 1 x 1 rib course and one interlocked (12).

Jersey Knitting. A method of knitting performed with a single set of needles (12).

Jersey Stitch. The jersey stitch is the basis or starting point of all knitted structures. The loops intermesh in one direction with the result that the fabric has one appearance on the face side and a wholly different one on the reverse side (12).

Moisture Content. The amount of moisture in a material determined under prescribed conditions and expressed as a percentage of the mass of the moist material, that is, the original mass comprising the dry substance plus any moisture present (11).

Moisture Regain. The amount of moisture in a material determined under prescribed conditions and expressed as a percentage of the mass of the moisture-free specimen (11).

Permeability. The rate of flow of fluid under a differential pressure through a material (11).

Tex Unit. A tex unit is equal to the mass in grams of one kilometer of yarn or other textile strand (11).

Thickness. The distance between one surface and its opposite; in textiles, the distance between the upper and the lower surface of the material, measured under a specified pressure (11).

Wale. Loops running lengthwise in a knitted fabric in the form of a ridged line; also known as the rib; corresponds to the warp in woven fabric (12).

Weft Knitting. A method of making a fabric by normal knitting means in which the loops made by each weft thread are formed substantially across the width of the fabric, characterized by the fact that each weft thread is fed more or less at right angles to the direction in which the fabric is produced (13).

Yarn Number. A measure of the fineness or size of a yarn expressed either as "mass per unit length" or "length per unit mass," depending upon the yarn numbering system. Direct yarn number (equal to linear density) is the mass per unit length of yarn. An indirect yarn number is equal to the reciprocal of linear density, and it is the length per unit mass of yarn (11).

Chapter 2

REVIEW OF LITERATURE

The importance of moisture transport properties of textiles as an important thermal factor in clothing comfort was established in Chapter 1. The review of literature will examine the following aspects: (1) clothing comfort, (2) history of moisture transport research, (3) moisture transport mechanisms and processes, (4) system variables--clothing, man, and the environment, and (5) test apparatus and procedures.

CLOTHING COMFORT

Clothing comfort can be considered as a functional aspect of dress (3, 14) which is related to physiological and/or psychological responses of the wearer. Clothing comfort is composed of many complexly related factors, both thermal and non-thermal. This research examined physiological responses of thermal factors, specifically that of moisture transport.

The concern for comfort and function in regular apparel has varied throughout history (4). Currently, other fabric properties, such as ease-of-care performance and aesthetic aspects seem to be more important. However, there does appear to be some renewed interest in clothing comfort, as witnessed by advertisements promoting comfort aspects and by the patent literature for finishing techniques which improve moisture transport.

Lennox-Kerr (15) reported that Dr. Mark said that it was time to improve psychological and physiological aspects since physical properties have been developed. Dr. Dichter (16, 17, 18), a psychologist and consultant to the textile industry, also encouraged the development of comfort and aesthetic properties of textiles. Hollies (19) advocated the improvement of clothing comfort in a logical manner.

The approach to studying and implementation of clothing comfort is varied. It has been suggested that clothing comfort is too complex to study. Kemp (5) said that something that can be identified can be measured.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) used a logical approach to examine the subjective opinion of room comfort. ASHRAE acknowledges that not everyone will be comfortable at the same environmental conditions (20, 21, 22). There will always be some who are too cold, while others are too hot. Realistically, the room must be maintained at one set of environmental conditions. ASHRAE's approach determines the environmental conditions which satisfy the largest number of people. Actually, they prefer that 80 percent of the subjects be comfortable.

This approach could be a logical one to use in studying clothing comfort. It must be realized that not everyone will be equally comfortable in the same fabric or apparel. The garment which makes the most subjects comfortable would be the best comfort choice.

McNall et al. (20) defined thermal comfort as satisfaction with the thermal environment. Ghosh (23) suggested that comfort was the absence of unpleasant sensations.

The importance of moisture transport properties of textiles is widely acknowledged (3, 4, 24, 25, 26, 27). Mecheels et al. (28:76) stated that "the ability of clothing to permit moisture transfer is an important part of the thermal regulation for the body-clothing-climate system." Goldman (29) suggested that at conditions of extreme heat, man becomes almost totally dependent upon evaporative cooling for maintenance of heat balance.

HISTORY OF MOISTURE TRANSPORT RESEARCH

As early as the fifth century, skin breathing was associated with the liberation of invisible perspiration, termed _perspiratio insensibilis_ in Latin. In the early seventeenth century, doctors stressed the need to keep the pores of the skin open to allow the escape of insensible perspiration. It was advocated that wool flannel be worn next to the skin to promote insensible perspiration (4).

At the end of the eighteenth century, Count Rumford exposed fabrics to damp atmospheres to determine their increase in weight. It was expected that the cotton fabrics would gain more weight than the wool fabrics, since they absorbed water more readily. From this experiment it was determined that this thinking had been in error (4).

In the nineteenth century, Coulier found that vapor absorbed by the fabric did not always cause the fabric to feel wet. Coulier was the first to distinguish between the moisture held in the fibers and the moisture held in the fabric structure. In the early twentieth century, Rubner was the first to study the role of fiber content and fabric structure in moisture transport (4).

Clothing physiology developed during the twentieth century when research was conducted to determine the suitability of clothing for the military man. This research reached a peak during World War II. Military research has also been conducted on clothing systems for man in space.

Renbourn (4) considers clothing hygiene to be a relatively young science. It should involve the textile technologist, biophysicist, physician, physiologist, and designer of textiles.

MOISTURE TRANSPORT MECHANISMS AND PROCESSES

This topic includes (1) transport mechanisms and the importance of each, (2) the moisture transport process, (3) driving forces, and (4) the evaporation process.

The four mechanisms responsible for moisture transport, both vapor and liquid forms, are (14):

1. Diffusion through interstices.
2. Fiber absorption-desorption.
3. Capillary transport.
4. Migration along the fiber's outer surface.

The number of mechanisms and the description and importance of each mechanism varies in the literature. The above list represents the most current and comprehensive view of moisture transport mechanisms.

One major source of variation concerning the list of moisture transport mechanisms centered around the third and fourth mechanisms listed above. The differentiation between capillary transport and migration along the fiber's surface is not always made (14, 26). This distinction is important for accuracy. Migration along the fiber's surface occurs along a single fiber; whereas capillary transport also relies on the formation of capillary tubes by two neighboring fibers or yarns.

The term wicking has been used to denote capillary transport and/or migration along the fiber's surface. A simple definition of wicking offered by American Fabrics (30:14) is "a quality of a yarn or fabric which enables it to draw moisture away from the body." Mark et al. (31:108) said that wicking is the "transport of liquids from a reservoir by fabric or yarn under the influence of capillary forces."

Each transport mechanism can be related to one or more of the fabric variables; in some instances one fabric variable is more important than another. Diffusion, which occurs mainly through large pores in the fabric, is strongly related to the fabric structure. However, the swelling of hydrophilic fibers can alter the diffusion process.

The fiber absorption-desorption mechanism is related to the fiber content. Hydrophilic fibers have been thought to be the most desirable, since they are the most absorbent. It has been suggested that the total fabric absorption capacity which relates also to fabric structure may be just as important.

Both migration along the fiber and capillary transport are related to surface wettability of the fiber.

Surface wettability is, in turn, related to the fiber content and finishes. However, capillary transport is also dependent upon the formation of capillary tubes. This is, in turn, related to yarn twist and fabric structure.

It is very difficult to predict how changes in the fabric components will influence moisture transport properties of a fabric. Qualitative and quantitative tests capable of measuring each moisture transport mechanism during the total transport period have not been developed.

In addition, it has not been possible to establish which mechanism or mechanisms are the most important. Previously, it was stated that certain moisture transport mechanisms were more important than others under all conditions. But it is now believed that the importance of mechanisms can vary with different fabrics and environmental and physiological conditions. The importance of various mechanisms can also vary at different times in the transport process.

The moisture form, vapor or liquid, can also be an important factor. Vapor transport utilizes only two mechanisms: diffusion and fiber absorption-desorption. Liquid transport can utilize all of the transport mechanisms. Liquid transport also involves vapor which is above the liquid surface. Liquid transport is more difficult to understand and to study, and has been studied less than vapor transport.

Opinions concerning the importance of the transport mechanisms vary. Diffusion, often thought of as a mechanism just for vapor transport, can also aid liquid transport. Mecheels (14) stated that diffusion is probably not too important unless air currents are present. Much research is performed in ambient air. Mecheels' statement suggests the importance of the use of various air velocities during testing.

The fiber absorption-desorption mechanism has been traditionally considered the most important transport mechanism (3, 4, 32, 33, 34). Current research findings have caused the role of fiber absorption to be reexamined (35, 36, 37, 38). It appears that other mechanisms are responsible for moisture transport through hydrophilic fabrics.

Confusion still exists concerning the importance of fiber absorption. Mecheels (14) said that fiber absorption-desorption was the basic transport mechanism for hydrophilic fabrics but not for hydrophobic fabrics. Mecheels (14) added that the importance of fiber absorption in liquid transport might be in quickly removing moisture transport from the surface of the skin. However, initial moisture pickup from the skin is not totally dependent upon fiber absorption.

It has also been suggested that fiber absorption-desorption is a slow and inefficient mechanism. Slow drying has been associated with undesirable subjective fabric/skin contact sensations.

Ghosh (23) said that the major mechanism for liquid movement is capillary transport. He does not differentiate between capillary transport and migration along the fiber's surface. Mecheels (14) said that the mechanisms of capillary transport and migration along the fiber's surface were underestimated.

Behmann and Meissner (26) state that when a hydrophobic fiber is used, the absorption-desorption mechanism is not used. Capillary transport then becomes the most important transport mechanism. Behmann and Meissner do not differentiate capillary transport and migration on the fiber's surface.

Each mechanism will be briefly discussed now that their relative importance and relationship to fabric variables have been examined. Diffusion is the escape of molecules from an area of high concentration to an area of lower concentration. Diffusion is also referred to as the random walk, because it results from the random motion of the escaping molecules.

The term sorption is used to indicate moisture takeup. Absorption means that the water is taken inside the fiber, while adsorption implies that it is taken up along the fiber's outer surface. Desorption, the giving up of moisture, is generally associated with moisture release from inside the fiber.

For absorption to occur, moisture must enter through the amorphous areas in the fiber surface. Moisture can only be absorbed in the amorphous areas of the fiber; it cannot enter the crystalline regions of the fiber, hence the low absorbency of polyester. Cross-linking resin finishes lower fiber absorption (28).

Absorption can also cause fiber swelling which can lead to blocking or jamming of the air spaces in the fabric structure (39). This can influence both the diffusion and capillary transport mechanisms. It has been suggested that absorption of liquid causes greater swelling than absorption of vapor (40).

Adsorption is related to the wettability of the fiber and influences capillary transport and migration along the fiber. If the surface of the fiber has high wettability, a bead of liquid will spread very rapidly. When the surface has a low wettability, the bead does not spread quickly.

Capillary transport is a principle used frequently in physics, biology, and botany. The principle is that the two surfaces must be almost parallel and close enough to form a capillary tube. Liquid must enter the tube, then it is pulled upward. This upward transport is aided by the attraction of the water molecules for the solid surface (41).

A surface which is highly wettable promotes rapid transport.

Capillary tube formation in fabrics can be between two fibers or two yarns. No definite guides concerning the yarn spacing and yarn twist for optimal capillary transport have been established. The general principle is that a narrower tube promotes greater transport (41).

The process of getting the liquid from the skin into the tube is also important. Fourt and Hollies (3) say that to start capillary transport, the tubes must be filled with water. Winch (42) adds that when the surface of the tube becomes wet, the ease of liquid transport increases.

Most of the literature is concerned with analyzing transport mechanisms instead of the complete transport process. The basic moisture transport process involves (1) the pickup of perspiration by the fabric, (2) transport through the fabric, and (3) evaporation to the outer environment.

The details involved in this basic process might vary for vapor and liquid transport. In liquid transport, the initial moisture pickup is influenced by the distance between the fabric and the skin or moisture. It will also be dependent upon the fabric structure for the number and type of skin/fabric contact points. The surface hairiness can also be a factor in the initial removal of perspiration from the skin.

Buras et al. (43) examined the skin/fabric contact points by using photography to determine where initial wetting of the fabric occurred. Buras et al. (43) suggested that the steps in the initial moisture pickup include: (1) initial wetting at contact points with water being drawn into the fiber bundle, (2) the filling of inter-fiber spaces, which is somewhat more rapid than the first step, and (3) filling until the walls of the tubes become wet, which allows the main flow to start.

The second step in the moisture transport process, transport through the fabric, is the step concerned with the moisture transport mechanisms. Examination of the moisture transport process and transport process which occurs in wet fabrics should be studied in more detail. After the initial moisture pickup, the fabric must transport the moisture quickly through the fabric to the outer environment for evaporation.

In hydrophilic fabrics, the initial pickup may be fast, but a slow transport through the fabric can cause the fabric to feel moist. This may produce an unpleasant subjective response. If hydrophobic fibers do not transport efficiently, a liquid film or water reservoir can form on the surface of the fabric. This can also cause an unpleasant response.

The third step in the transport process, the evaporation of perspiration from the fabric to the macroenvironment, is not well defined. The location of evaporation of perspiration can occur (1) within the fabric structure, or (2) at the fabric's upper surface. The location of evaporation relates to the amount of evaporative cooling the subject receives. When evaporation occurs near the skin, more evaporative cooling is realized. The determination of the location for evaporation of perspiration relates to (1) fabric structure, (2) size of interstices, and (3) fabric thickness.

In stepwise chemical reactions, the slowest step is the rate-determining step. The concept of rate-determining steps has been mentioned in relation to moisture transport. Not all of the transport mechanisms are necessary for sufficient transport to occur in textiles. Therefore, this situation is different from a reaction where all the steps must occur for the reaction to be complete. In moisture transfer, a slow mechanism could actually be countered by a fast mechanism occurring simultaneously, or during another portion of the transport process. This would not necessarily result in a decrease in rate of moisture transport. Buras et al. (43) said that the initial resistance to wetting can slow down the transport rate.

A logical approach to increasing the rate of transport would be to develop a fabric which would efficiently remove the moisture quickly from the skin and provide transport for quick evaporation into the macroenvironment.

The concept of driving forces has been used to examine moisture transport through textiles. Hardy et al. (44) says that evaporative cooling occurs only when driving forces move the moisture from the skin's surface, through the fabric, and to the macroenvironment for evaporation. Gagge et al. (45) mentions the importance of the vapor gradient, which is the difference in vapor or relative humidity at the microenvironment and the macroenvironment. Temperature or pressure gradients are also cited as driving forces (3, 4, 44, 46).

Evaporation of perspiration into the macroenvironment is necessary to obtain the cooling effect which aids in the maintenance of thermal balance. Evaporation is the escape of molecules from an area of high relative humidity to an area of lower relative humidity. The evaporation process creates a cooling effect due to the latent heat of vaporization which is the basis for heat balance. Water absorbs a large quantity of heat during the change to vapor form. The heat of vaporization is approximately 580 kilogram calories/hour for each gram of water evaporated (3, 4).

The evaporation process is influenced by various environmental factors. Four general methods suggested for obtaining a rate increase are the following (47): (1) increase convection currents, (2) increase heat, (3) lower atmospheric pressure, and/or (4) increase surface area.

In improving moisture transport through textiles, this approach has not been used. However, in many cases it is not possible to control the first three which are environmental factors.

The fourth method of increasing surface area was briefly mentioned. When a vessel increases in diameter, the transport rate should increase. However, this approach may not be totally correct for textiles. An increase in the surface area of the fibers may not result in an increase in transport rate. In many cases evaporation is thought to occur at the fabric's upper surface. An increase in the fiber surface may not result in an increase at the fabric's upper surface. For example, a doubleknit fabric would generally have more fiber surface than a single jersey knit. However, the bottom portion of the doubleknit where the increase is located may not be where evaporation occurs.

Condensation is the opposite of evaporation which means a change from the gaseous state to the liquid state. Insensible perspiration can condense in the microenvironment, the fabric structure, or inside the fiber.

SYSTEM VARIABLES

Man, clothing, and the environment function as a system to control body temperature. Each of these major variables is composed of several factors, which influences moisture transport. Table 1 lists variables related to environmental, physiological, and clothing variables. Each major variable will be discussed in this section.

Environmental Variables

Environmental factors include relative humidity, temperature, air currents, and atmospheric pressure. However, in recent textile literature, there has been use of the terms microenvironment and macroenvironment to distinguish the conditions between the skin and the fabric from those of the outer environment. This is a good distinction for use in moisture transport discussions, because in most cases the environmental conditions are not the same at both environments. The differences in environmental conditions create gradients which can act as driving forces for transport. The microclimate has often been viewed solely as a physiological variable. The relative humidity in the microenvironment often exceeds that of the macroenvironment because insensible perspiration condenses, thus causing the relative humidity at the microenvironment to increase.

Table 1

Moisture Transport System Variables

I. Environmental Variables

- relative humidity
- temperature of environment
- air currents
- atmospheric pressure

II. Physiological Variables

- body temperature
- metabolism
- activity level
- surface area
- perspiration--type, amount, location

III. Clothing Variables

A. Fabric

- fiber content
- yarn structure
- fabric structure
- finishes
- basic fabric properties

B. Apparel

- style
- fit
- number of layers--fabric and air
- closures and vents

The importance of temperature and atmospheric pressure were discussed in relation to driving forces and rate-determining factors.

Moisture transport research examines mainly vapor transport at standard environmental test conditions using ambient air. Convection is often studied separately from moisture transport. Convection currents could perhaps aid evaporation by carrying vapor away from an area and replacing it with drier air.

In general, air movement has been associated with an air current moving over the fabric. However, when the body is in motion, the fabric slides across the air in a similar manner. Gregory (48) cites the importance of these two effects. The pumping action of the body can also influence these forces; this effect is often termed ventilation or bellows effect (48, 49).

Leach (2) found that little of the air movement occurred at the microenvironment when air currents up to 15 kilometer/hours were used. This suggests that air currents function mainly near the upper surface of the fabric. Leach also suggested that air currents may aid the wicking mechanism as well as the diffusion mechanism.

Physiological Variables

Vokac et al. (50) studied subjects during periods of motion, followed by periods of nonactivity. It was found that when the subject's activity stopped, the relative humidity at the skin's surface increased rapidly and the heat flow from the body greatly decreased.

Leach (2) views the body as a complex heat and energy producing machine. However, it must be remembered that man's responses to the thermal environment are both physiological and psychological (3, 4, 51). In many cases the two responses are difficult to separate. Some processes such as perspiration, once thought to be purely physiological, are now being found to also be related to psychological responses. Physical tests in the laboratory are related to the physiological aspects. When subjects are used, it is usually impossible to separate the psychological and physiological responses.

Regulation of the body temperature can be achieved by the following methods (52): (1) control of blood flow to skin, (2) control of sweat production, and (3) control of metabolic heat production by shivering. Goldman (29), Rothman (46), and Winslow et al. (53) said that at high temperatures or activity levels, the body relies heavily on sweat production and evaporation to maintain the body temperature.

Rotham (46) said that between the range of 25-31°C. (77-88°F.), a subject at normal activity level can easily maintain heat balance by controlling blood flow. Between 31-32°C. (88-90°F.), the blood flow reaches its maximum, and sweating occurs; this is the zone of evaporative regulation. Rothman (46) also said that between 31-36°C. (88-98°F.), evaporative heat loss can maintain normal body temperature.

The maintenance of body temperature is stressed in maintaining heat balance. But the external and internal body temperatures can vary greatly. The external skin temperature is not so crucial for maintenance of heat balance as is the internal body temperature. The internal temperature must be maintained within as small a range as 37°C. (98.6°F.). When internal body temperature increases, heat stress and eventually death can result. Brouha et al. (54) says that there are several ways to measure heat stress, including measurement of rectal temperature and the change in body temperature.

Although heat stress might not occur, the subject can feel very uncomfortable. Ghosh (23) said that the subject is generally comfortable between 31.11-33.33°C. (88-92°F.), but that below 31.11°C. (88°F.), the subject is too cool, and above 33.33°C. (92°F.) the subject is too warm. Goldman (29) said that the skin temperature of sweating man is 35°C. (95°F.).

The body's thermostat, the hypothalamus, is located at the base of the brain (4, 46, 55). It is believed that the anterior portion controls the heat dissipation; therefore, it would be stimulated by warm sensations. The posterior portion controls heat conservation, and it is stimulated by cool sensations. Hot and cold thermoreceptors which are located in the dermis receive skin sensations, and then send signals to the hypothalamus. Rothman (46) said that the sensory thermal thresholds are lowered when the horny layer of skin is moist. Perhaps this helps explain why subjects feel uncomfortable when the skin is moist.

Hendler and Hardy (56) said that temperature sensation is not yet fully understood. People do react differently to the same environment. Dill et al. (57) divide subjects into five categories based on their sensitivity to temperature.

Acclimatization is the body's response or adaptation to new stimuli, either hot or cold. For example, in hot climates, the sweat capacity of the individual increases as acclimatization to heat occurs (46). This functions to increase the heat loss by increasing the evaporative cooling.

The basal metabolism relates to the rate of energy or heat production resulting from the oxidation of food (46, 52). The metabolic rate is influenced by age, size, sex, activity level, and the internal body temperature (52). Average energy production varies with activity level from approximately 330 British thermal units per hour during sleep to 900 British thermal units per hour during a slow walk (52). At increased activity levels, increased heat dissipation is needed to maintain comfort and thermal balance. Vokac et al. (50, 58) found that the activity level is an important influence on the relative humidity and temperature at the skin or microenvironment.

Various aspects of perspiration include the type, amount, and related problems. Woodcock (59) said that man can secrete enough perspiration to control body temperature if evaporation occurs. This makes clothing an important consideration.

Perspiration can occur in vapor and/or liquid forms due to variations in man's activity level and/or environmental conditions. The vapor form, termed insensible perspiration, comes through the skin which is functioning as a semipermeable membrane (60).

Herrman and Kanof (61) said that there is no sharp distinction between sensible and insensible perspiration. When vapor form condenses to liquid form, it is not technically considered sweat. Peters (62) said that sweat or sensible perspiration is liquid secreted from the sweat glands in the skin. Sweat glands start functioning when heat production increases and when insensible perspiration is not sufficient for cooling the body.

Peters (62) said that sweating generally starts at 31°C. (87.8°F.); slight activity or clothing can cause it to start at 26-28°C. (78.8-82.4°F.). Rothman (46) cites the onset of sweating at between 31 and 34.5°C. (73-86.6°F.).

Sweat or sensible perspiration is a fluid excreted by the sweat or sudoriferous glands, which are located beneath the skin's surface (63). Ducts open onto the skin to allow drops of sweat to emerge. When sweating becomes heavy, the drops join to form a liquid film.

The main function of the sweat glands is to aid the regulation of body temperature. However, not all sweating is thermal; emotional conditions can also create "nervous sweat" (64). Although nervous sweat is not necessarily needed for thermal comfort or evaporative cooling, the excess liquid secreted must be evaporated to maintain comfort. Nervous sweating starts suddenly, and it often appears first at the hands and armpits (61).

Sweat is composed of 98-99 percent water (63, 64). Sodium chloride is the most concentrated solute present (64). Most water-soluble substances which occur in plasma can be present in sweat; this includes both organic and inorganic compounds. Lactic acid controls the pH of the solution.

The amount of perspiration varies with environmental conditions, activity level, and area of the body. The amount of sweat varies for different areas of the body due to the variation in the number of sweat glands. A low sweat rate of 1 to 2 grams per hour occurs at the back, arms, forearms, and buttocks. The neck has a moderate sweat rate of 4 to 5 grams per hour.

The armpit and groin areas have a high sweat rate; they also present special transport problems because of their location. The armpit area can vary from 0 to 7 grams per hour (52). Whenever perspiration is not removed, the total area covered with perspiration increases. It appears that fabric and apparel should be capable of transporting the maximum amount of perspiration expected for given environmental and physiological conditions.

An unclothed subject at 20-32°C. (68-89.6°F.) produces approximately 100 grams of perspiration while walking. When the temperature increases to 37°C. (98.6°F.), production of 1 to 2 liters per hour is common. Production can go as high as 3 to 4 liters per hour for short time periods (2).

Goldman (29) said that the average army man has a skin area of 1.8 square meters. Whelan et al. (65) said that at normal conditions an average of 15 g/m^2/hr. is common; in hot environments during activity, production can exceed 100 g/m^2/hr.

Heat loss must approximate heat production for the body to remain in thermal balance. Approximately 580 calories of heat are absorbed per gram of perspiration evaporated. This is at ideal conditions, which represent the maximum cooling obtainable.

Clothing Variables

The two major divisions of this category are (1) fabric variables, and (2) garment variables. This research examined the two major fabric variables, fiber content and fabric structure. Other variables listed in Table 1 will be discussed.

The designer of textiles and clothing should determine the range of environmental and physiological conditions expected during garment wear. The designer must then manipulate the various textile and clothing variables to obtain comfortable apparel.

Clothing, our second skin, generally offers more resistance to moisture transport than does an equivalent layer of still air (66). Therefore, clothing is considered a barrier to moisture transport and evaporative cooling. Clothing also decreases the cooling effects due to air currents (51).

Fiber content. Differences in the ability of different generic groups of fibers to transport moisture is related to two fiber properties: (1) fiber absorption, and (2) fiber adsorption or surface wettability.

Fiber absorption is the fiber property most often considered because it is associated with the popular absorption-desorption transport mechanism. Surface wettability was discussed in relation to the transport mechanisms of capillary transport and migration along the fiber's surface.

Differences in the amount of fiber absorption do exist for different generic groups. At standard conditions, mercerized cotton fibers absorb 10.3 percent, while polyester fibers absorb only 0.4-0.8 percent (67).

Mecheels et al. (28) found that regular cotton absorbed 7.5 percent, but resin-treated cotton fabric absorbed 6.9 percent. It was also found that the finish reduced the amount of longitudinal fiber swelling. The rate of moisture transport was not reduced by the finish. Cross-linking resins lower the absorption of cotton (68, 32). A finish which reacts with the fiber, such as a cross-linking resin, is considered a fiber aspect in this research.

Mecheels (14) said that fiber absorption is of little importance in moisture transport through the fabric; it was suggested that wettability was more important. Other problems associated with absorption include objectionable hand of wet fabrics and slow fabric drying.

Consumer surveys show that the consumer associates a comfortable fabric with absorptive fibers. Kemp (5) found that English consumers generally associated natural fibers with comfort and synthetic fibers as uncomfortable. Kemp also found that some consumers express a dislike for finished cottons.

Cotton Incorporated (69) reported that a survey performed for them by Opinion Research Corporation found that 85 percent of the consumers ranked comfort above value, durability, and shape retention as the property they considered most important when purchasing apparel. The term comfort was interpreted by each consumer. The survey also found that the consumer believed cotton fabrics were cooler than polyester fabrics.

Cotton Incorporated now uses the comfort factor in advertisements and promotions. The recent introduction of cotton top panty hose and other cotton items also promotes the comfort factor (70).

Before the acceptance of knit outerwear, cotton dominated the knit market (71). Synthetic fibers offer dimensional stability and ease-of-care properties in knits. Reichman (71) believed that synthetics lack the moisture absorbency and comfort properties that cotton possesses.

Ludewig (72:418) said, "Polyester fabrics impair perspiration, since they do not absorb this and cannot conduct it toward the exterior where it can evaporate." Both opinions tend to ignore the surface wettability, an important fiber property.

Morris (73) said that polyester is uncomfortable because of its low absorbency. Hollies (19) believed that fiber absorption is of little importance compared to surface moisture. Lennox-Kerr (15) reported that at a conference, Mecheels said that man-made fibers can be satisfactorily used in tropical clothing.

Behmann and Meissner (26) believed that differences in research findings concerning the role of fiber in moisture transport may result from the environmental conditions used in the tests. It was suggested that the findings of Renbourn (4) and Werden et al. (74) may be due to the moderate environmental conditions used in their research. Both research projects (4, 74) found no differences due to fiber content. Behmann and Meissner's (26) research comparing wool and nylon at more severe environmental conditions found wool to be superior to nylon.

Renbourn (4) discussed an army experiment which used subjects in a controlled environmental laboratory and in a field test in the desert. The traditional wool sock was compared with the newer polyester sock. The study found that the polyester sock held less moisture than the wool sock, but that polyester socks wicked better than wool. Both socks were found to be equally comfortable in subjective testing. The army adopted the polyester socks (4).

Knight (7, 8) compared various blend levels of two single weft knit structures. Knight concluded that fiber content was not important in moisture transport.

Consumer publications have examined performance, including comfort, of men's t-shirts (75, 76, 77). Cotton was the traditional fiber used in t-shirts, but now it is blended with polyester to improve dimensional stability. Consumer Reports (77) said that cotton shirts can absorb more perspiration than cotton/polyester blends. This statement was based on fabric absorption and not on moisture transport tests.

Cotton was used almost exclusively in knits when knit fabrics were limited to underwear. Synthetics and blends are currently used more in outerwear apparel fabrics than cotton.

The concept of blending to improve properties is not new. No fiber is perfect; therefore, blending might improve total performance. However, little attention has been given to the use of blending to improve comfort properties.

Various charts, prepared for use in blending fibers, list the advantages and disadvantages of each fiber for various properties. Comfort is usually not listed as one of the properties. Segall (78) ranked cotton the highest and polyester the lowest in relation to comfort.

Blending is just beginning to be viewed as a possibility for improving comfort performance of clothing. Hoffman and Peterson (79) said that the expected performance was that the addition of hydrophilic fibers would improve the comfort of hydrophobic fibers. Few expected that blend fabrics could be more comfortable than hydrophilics.

Hoffman and Peterson (79) used persons to determine the comfort of polo shirts of 100 percent acrylic, 100 percent cotton, and an acrylic/cotton blend. The blend shirts were found to be more comfortable; however, various comfort aspects were included in subjective responses. Hoffman and Peterson's explanation was that synthetic fibers wicked and promoted drying, while the only credit they gave the hydrophilic fibers was the prevention of clinging.

Ghosh (23) also believed that blending may help create fabrics with improved moisture transport properties. His reasoning was that the hydrophilic fibers will promote wicking while holding less water in the fabric. This would prevent an undesirable skin/fabric contact sensation. He, too, believed that cellulosics would prevent the clinging associated with static electricity.

Perhaps another approach to improving moisture transport properties by blending would be to (1) increase the number of transport mechanisms functioning, and (2) insure that each step in the moisture transport process occurs efficiently. The cotton or hydrophilic fibers could transport moisture via the absorption-desorption mechanism. In addition, the polyester or hydrophobic fiber could transport via the capillary transport and migration along the fiber's surface mechanisms.

Cotton Incorporated (80, 81) is currently promoting "natural blends" which contain a minimum of 60 percent cotton. Cotton Incorporated (82) said that 100 percent polyester has poor comfort properties, which are improved by blending with cotton.

Harper (32) at the Southern Regional Research Center found that fabric moisture regain decreased as the amount of polyester increased. The results seemed logical; but the use of this test as an indicator of comfort has been questioned.

In addition to the chemical nature of the fiber, the following factors are associated with the fiber variable: fiber diameter, fiber cross-section, fiber crimp, and fiber length. Modifications in cross-section might influence migration along the fiber's surface. The fiber length which has been associated with surface hairiness might aid in the initial removal of perspiration from the skin.

Mark et al. (31) said that textured polyester fibers wick better than untextured polyester fibers. If the fiber surface was initially wettable, as in polyester fibers, texturing will increase transport. But in fibers with a low surface wettability, the crimp does not increase wicking.

Yarns. Yarn variables which relate to moisture transport include the yarn's twist, shape, and diameter. The role of yarn variables was not discussed extensively in the literature.

The role of yarn twist relates to (1) the formation of capillary tubes between the fibers in the yarn, and (2) the surface hairiness of yarns made from staple fibers.

The organization of fibers within the yarn can also influence capillary transport rate. The less organized fibers in carded yarns perhaps have a slower transport rate than the more organized fibers in a combed yarn.

Generally, spun yarns used in knit fabrics have a lower yarn twist than yarns used in woven fabrics. Cotton and cotton/polyester staple yarns used in knits are generally combed (83). Polyester fabrics generally use a textured polyester multifilament yarn with low or no twist.

Fabric structure. The following fabric structure factors can influence moisture transport: basic fabric structure, yarn count per unit area, and the size, shape, and location of the interstices.

The fabric structure can influence the mechanisms of capillary transport and diffusion. The role of convection currents is also influenced by the fabric structure. The relationship of moisture transport to fabric structure is an important one.

Fabric structure has generally received less attention than fiber selection. For those preoccupied with absorbency, it should be remembered that the fabric structure can also influence the total fabric absorption.

Research concerning the role of the fabric structure shows that it is an important variable. Renbourn (4) said that it may be more important than fiber content (4). Buras et al. (43), in their study of woven cotton, thought that the transport rate was more of a function of fabric structure than the quantity of cotton in the structure.

Most research has been conducted using woven fabric structures. Differences exist in the basic nature of the woven and knit structures. Therefore, it is uncertain if basic research findings regarding fabric structure using woven fabrics can be applied to knit fabrics.

For example, in woven structures, tight structures offer a higher resistance to vapor transport than loosely woven structures. A basic guide when using hydrophilic fibers suggests the avoidance of tightly woven structures to allow sufficient transport through the interstices. But even in the tightest weft knits, there is more openness than in a tightly structured woven fabric.

Differences also exist in terminology and production of woven and knit structures. The formation of a woven fabric is based upon the interlacing of warp and weft yarns. The formation of the interstices in a woven fabric and their resulting size and shape is related to the type of weave and the number and size of the yarns.

Gan (84) said that the knit geometry is more complex than woven fabric geometry. Formation of weft knits is based upon an interlooping process involving one yarn set which interloops horizontally across the fabric. The basic weft knit loop is the same for the jersey and interlock structure. Whether the knit is a single or double structure greatly influences the amount of interstices.

The interstices of the knit structure vary greatly, especially in shape, from those of the woven fabrics. The amount of air contained in the fabric structure also varies more for wovens than for knits. Woven fabrics can have a wider range of compactness from open tight than knits. In general, knits contain more air than woven fabrics. In addition, the closeness of the yarns in a knit structure plus the size of yarns and number of wales and courses per unit area have an influence.

Gregory (48) said that resistance to flow is not dependent upon the number, size, or shape of the interstices, as many think. Gregory thought that as the size of the interstice decreased, the flow rate increased. When there are a large number of interstices in a given area, interference is created by the surrounding holes which reduce flow.

Penner and Robertson (85), in later research, studied variation in weave structure by using models of various structures. It was found that even when the area of the interstice was the same in the various structures, the flow was not the same. Penner and Robertson concluded that the shape of the interstice and not the area was the important factor.

Clulow (86) studied the interconnections of interstices. He said that two fabrics with the same porosity could have different permeability measurements because of the manner in which the interstices were distributed within the fabric and their interconnections. Clulow said that the permeability of fabrics with a great number of small holes can be either more or less than a fabric with a small number of large holes. No guides regarding the size and shape of interstices in knit fabrics for production of fabrics with good transport abilities were presented in the literature.

Latham (87) noted that transport differences could result between knit wales and courses. In the weft jersey, wales appear on the technical face and courses on the back. In a double weft or interlock structure, wales appear on both the face and the back.

Knight (7, 8) found that the jersey weft knit structure transported more vapor than the rib weft knit structure. In other studies using knits, such as the ones mentioned using socks and t-shirts, only one knit structure was used while the fiber content was varied.

Mecheels (14) suggests that the direction of the yarn axis in the fabric may be important in the absorption-desorption and capillary transport mechanisms. He suggests that a maximum number of capillaries should be located at an acute angle to the surface of the fabric. Mecheels did not offer any guides for achieving this.

Finishes. Certain chemical or physical finishes can alter moisture transport mechanisms. For example, diffusion can be altered by either sizing, which clogs the interstices, or calendering. These finishes can also influence the capillary transport mechanism.

The fiber absorption-desorption mechanism can be altered by finishes which react chemically with the fiber, such as a cross-linking durable press resin. This cross-linking results in reduced fiber absorption.

Surface wettability can be changed by chemical finishes. Finishes such as humectants increase wettability; whereas water repellent finishes reduce wettability. Changes in wettability influence capillary transport and migration along the fiber surface.

Currently, most polyester knit fabrics receive no chemical finishes. They are tentered and heat set to insure dimensional stability.

Cotton and cotton/polyester knits receive a resin finish to increase dimensional stability. Dimethyloldihydroxyethyleneurea (DMDHEU), a durable press resin, is used frequently on knit goods (88, 89). The pad/dry/cure process is generally used (90). Addition of polyester is recommended for resin-treated cotton knits to increase abrasion resistance.

Fabric properties. Various fabric properties have been associated with moisture transport. In some cases, the determination of fabric properties has been used as a quick indicator of moisture transport. The use of these properties as an indicator of moisture transport properties is perhaps because no standard test method exists for determination of moisture transport.

The examination of fabric properties may offer a new approach to the study of moisture transport, because fabric properties can be influenced by one or often several of the fabric variables previously discussed. Fabric properties associated with moisture transport include: absorbency, air permeability, thickness, weight, density, porosity, surface area, and surface hairiness. More research is needed to establish the actual relationship of these fabric properties to moisture transport.

The association with absorbency is expected, since so much emphasis has been placed on the fiber absorption-desorption mechanism. Some researchers measure fiber absorbency, while others examine total fabric absorbency.

Fiber absorption makes the hydrophilic fibers appear more desirable than hydrophobic fibers. Fabric absorption relates to the fiber content and fabric structure.

The use of absorbency has been criticized, because it does not measure other transport mechanisms. Leach (2) added that the transport of moisture is the important factor, not the storage in the fiber or fabric structure. Leach also said that storage can create an unpleasant skin/fabric contact sensation.

Air permeability is the ability of a fabric to allow air to pass through the structure. An open fabric structure usually offers less resistance; therefore, it would allow more air and perhaps more moisture to pass through it. Open fabrics generally have a higher air permeability index than compact fabrics. Air currents may increase the rate of evaporation, particularly in an open structure. A fabric with a high permeability index would be desirable when the fabric is made from hydrophobic fibers.

Mecheels (14, 35) believed that the popular concept of "air permeability=moisture permeability=comfort" was related to the diffusion mechanism. This concept may be true only on a limited scale. It relates back to the importance of the diffusion mechanism. The concept may be true when the fabric structure is more open, which would allow air currents to more readily aid evaporation. Ghosh (23) and Rees (91) said that vapor and air permeability are not identical. Vapor can pass through the fiber and the interstices in the fabric structure; whereas air can pass only through the interstices in the fabric structure.

Variables which influence air permeability include the fabric structure and, to a lesser extent, fiber length, yarn structure, and finishes that block interstices. Backer (92) cited the importance of the number and size of the interstices in air permeability.

Porosity has also been associated with vapor and air permeability. Porosity is the total void space or amount of air contained in the structure in relation to the total volume of the structure. Backer (93) said that textiles generally contain a large amount of air in their structures. Kanagy (94) also cited the importance of porosity to moisture transport through leather.

Porosity differs from permeability. Porosity represents the total air space available for flow. But the permeability value is a measurement of the flow that actually occurred. The area used for the actual flow may differ for various fluids, depending upon whether they are air, vapor, or liquid. Porosity can be influenced by whatever influences the formation of the interstices, which includes fabric structure and yarn size.

Fabric thickness has been used as an indicator of resistance to moisture flow or transport. Renbourn (4) said that the greater the thickness, the greater the resistance to vapor passage. Fourt (95) said that moisture transport is related to the thickness and tightness of the fabric structure.

Mecheels (96) said that heat and moisture permeability is influenced by the fabric's thickness. He adds that any fabric component which influences the thickness becomes an important variable. In knits, the type of knit, single or double, greatly influences the thickness. The yarn size can also influence the thickness, but in knits the yarn size range is small.

Fabric weight has also been associated with moisture transport. This implies that the more fiber in the structure, the higher the fabric weight. An increase in fabric weight suggests a decrease in transport. An increase in fiber might also decrease the amount of air in the structure. Backer (93) said that less air would result in reduced air flow.

Fabric weight was first used as an indicator of moisture transport before the introduction of the lightweight synthetics. With the difference in weight of synthetic and natural fibers, weight would not appear to be a good indicator, especially when comparing fabrics of different fibers.

Density or weight per unit thickness has also been used as an indicator (97). It is a somewhat more comprehensive property, since it encompasses both thickness and weight.

Surface area was cited by Leach (2) as a factor. Surface area was mentioned during the discussion of methods of increasing evaporation rate. It was pointed out that an increase in fiber surface area might not result in an increase in transport rate. Ghosh (23) said that a large surface area acts as a brake on air passing through the fabric.

Surface hairiness has been mentioned previously in relation to fiber length and yarn type. Finishes such as napping or fabric structure can also influence surface hairiness.

In some fabrics, fuzz will appear on only one side of the fabric. If fuzz is on the back side of the fabric and is close enough to make contact with the skin or perspiration, it can aid in the initial removal of moisture. It might also relate to transport through the fabric and evaporation from the fabric's upper surface. Surface hairiness also influences the warmth or coolness of the fabric to the touch.

Bogaty et al. (98) said that wicking and drop absorption rates vary inversely with surface hairiness. Therefore, an increase in surface hairiness would result in a decrease in wicking and drop absorption rates.

Apparel. The fit, style, and number of fabric and air layers relate to the garment variable. These factors will not be discussed in depth, since this research examined only the moisture transport properties of fabrics.

Watkins (99) urged home economists to become involved in the design of functional and comfortable apparel. Function design of apparel must consider both the fabric and garment variables plus use conditions. Black and Matthew (33) said that the biggest mistake in designing clothing for comfort is the lack of ventilation openings in the garment.

Fit is important, according to Gilling (100) and Fourt and Hollies (3). Stretchable knit apparel can fit closer to the body than woven garments. Close fit might improve the initial moisture pickup from the skin. Distortion of the knit structure can also result from a tight fit. Distortion can change the size and the shape of the interstices which could influence moisture transport.

The recent trend of wearing fewer layers of clothing could also influence moisture transport. The wearer can modify moisture transport by rolling up sleeves, by removing layers of clothing, or by opening closures.

New developments. New developments which could improve comfort center mainly around progress in fibers and finishes. In most cases these developments were not originally made to improve comfort aspects.

Hollow fibers have been developed, and they are used mainly in medical application. The possibility of using hollow fibers to improve comfort is being considered for the future (101, 102). The hollow fiber would allow water to travel up the center of the fiber in addition to along the sides. The hollow fiber might also improve the initial moisture pickup from the skin.

New chemical groups can be introduced into the basic polymer, or finishes can be added to the fiber (23, 103, 104). Telcon TGF from DuPont (105) was originally developed as a soil release and anti-redeposition agent. DuPont found that it also improved the wicking rate of polyester fabrics. DuPont claimed that the wicking rate of polyester fabrics is increased ten times (105). Other chemical finishes which claim to improve the wicking rate of polyester fabrics include Cooliecloth from Arkansaw Chemicals, Fantessa from J. P. Stevens, and Refresca from Spring Mills. The patent literature also indicated an increase in finishes which improve moisture transport (106, 107, 108).

Open-end spinning and other new methods of yarn formation might influence moisture transport. New methods of fabric formation, such as non-wovens, should also be considered.

Design guidelines. From the review of fabric variables and properties, no concrete guidelines are available for designing knit fabrics which maximize moisture transport. Some general recommendations are made; however, many contradictions appear.

Leach (2) recommended the following for clothing in a hot, humid climate:

1. Good wicking ability to remove perspiration from the skin.
2. Rapid drying fabric to prevent objectionable skin/fabric contact sensation.
3. Porous structure with high air permeability index.
4. Lightweight fabric and assembly.
5. Loose fit to promote convection.

TEST APPARATUS AND PROCEDURES

Several test methods and various types of apparatus have been developed to examine moisture transport properties of fabrics. Test apparatus and procedures range from simple to complex. No standard test method has been adopted in the United States. Several have reviewed various moisture transport test methods and apparatus used (3, 4, 109, 110, 111, 112).

It appears that many moisture transport tests do not replicate wear conditions. Some of the tests do not allow for measurement of all transport mechanisms. The major moisture transport test will be reviewed. The determination of basic fabric properties, which are often used as indicators of moisture transport, will be discussed later in this section.

If the producer of textiles and clothing is going to consider comfort aspects, test apparatus and a test method must be available. It must not be too complex or time-consuming to perform, and the apparatus must not be too costly.

Greenwood (9, 113) stated that a test for textiles should be simple. It must also be for materials which offer a relatively low resistance to moisture transfer as opposed to packaging materials which offer a high resistance. Greenwood added that the test need not fully duplicate all physiological and environmental conditions to be useful and accurate as an indicator of moisture transport.

Greenwood stated that to determine the comfort performance of a textile product, one must decide the following:

a) What properties to measure,

b) How to measure these properties,

c) What units to use in expressing the results of measurements,

d) How to describe the conditions of use of the product, and

e) How to translate the results of his measurements into a measure of comfort performance under particular conditions of use. (9:1)

There are various approaches to moisture transport research. Much of the research determines physical properties of fabrics in the laboratory under controlled conditions. This approach measures only the physiological aspects of comfort related to moisture transport.

Researchers have also used subjects in either a controlled environment or in field trials. The results using subjects include psychological and physiological responses. Some researchers have tried to determine whether laboratory tests of physical properties of textiles and tests using subjects correlate. Additional methods include the use of equations and computer modelling to predict moisture transport and comfort.

Moisture Transport Tests

Many of the tests examine vapor transport. These tests are based on the measurement of a volumetric or gravimetric loss for a given time period.

Two gravimetric methods used include (1) a water-filled vessel, and (2) a desiccant-filled vessel. The water-filled vessel method is used most frequently. It is also known as the dish method, control dish method, or Whelan control dish method (3, 4, 27, 65, 110, 113, 114). The Canadian standard test method (10) uses the dish method.

Other tests performed on leather, plastics, paper, and packaging materials use a similar vessel test (115, 116). The American Society for Testing and Materials (ASTM) has standard test methods for packaging materials (117, 118).

Various types of vessels have been used; any noncorrosive material is suitable. Custom Scientific Instruments offers a vessel called the vapometer. Generally, the vessel has two rings, the same outer diameter as the vessel, for use in specimen mounting.

This test method is fully explained in several articles (10, 65, 112, 114). The basic test involves gluing the fabric test specimen to the ring holder. This specimen is placed above the vessel which is filled with distilled water. The amount of evaporation which occurs during a given time period is determined by weighing the entire assembly.

Another version of the test adds a tightly-woven hydrophilic fabric over the test specimen. The test performed without the test specimen serves as a control. Variations in the distance between the test fabric and the water level determine the effect of the thickness of this air space.

Generally, this test is performed at standard textile test conditions of $21.1^{\circ}C. \pm 1.1^{\circ}C.$ ($70 \pm 2^{\circ}F.$), 65 percent relative humidity in ambient air. The data are reported as the resistance of the fabric to vapor transport or as the resistance offered by the fabric in an equivalent amount of still air. Resistance units are difficult for textile and clothing designers to interpret.

One problem with this method is the difficulty of obtaining accurate measurements. Another criticism is that the distance between the test specimen and the water level does not remain constant throughout the test period. Weiner (119) also said that the air layers within the system offer additional resistance.

Pierce, Rees, and Ogden (120) at the Shirley Institute developed a volumetric method in 1945. The method was based on a water-filled vessel attached to a capillary tube placed even with the water level of the vessel. The vessel was covered by a cellulose acetate film; this film allowed the vapor to pass, but prevented the fabric from becoming wet. Rees (121) continued to use this method, but it has not been used recently. Newns (109) cites this method and apparatus.

Another volumetric method for determination of vapor transport uses a perforated plate, generally sintered steel, connected to a water supply (14, 29). Various materials have been used to cover the steel plate. Hardy et al. (44) used chamois; Goldman (29) tried a cotton fabric. These materials added to the resistance of the test fabric, thus reducing the accuracy of the test. The bare plate has also been used in direct contact with the test specimen.

Mark et al. (122) said that similar devices have been used to determine both dry and moist heat transfer. The amount of heat loss by conduction and evaporation can be determined. Hock et al. (123) investigated the thermal properties of moist fabrics using a similar apparatus. Cohen and Baker (124) developed an instrument to measure moist and dry heat transfer.

It is often desirable to study more than one method of heat transfer at a time. But the simultaneous study of conduction and evaporation of moisture may not be necessary for textiles used in hot climates. It was mentioned previously that at high temperatures or high activity levels, evaporation is the most important method for controlling heat balance. The loss by conduction under these conditions is small. It appears that it might be more important to examine convection in conjunction with evaporation at these environmental conditions.

One of the first liquid transport methods by Larose in 1942 was reviewed by Buras et al. (43) and Newns (109). The apparatus was a porous plate which was in contact with a water supply. The fabric was placed directly in contact with the moist, porous plate.

Buras et al. (43) at the Southern Regional Research Laboratories said that Kettering, at the same institution, modified Larose's method. Kettering added a calibrated side arm which supplied the water. Buras et al. (43) developed a method using a glass filtering funnel to provide a wet porous plate; a flowmeter supplied a constant flow of water.

More recently at the Southern Regional Research Center, the "sponge wick" method has been used to determine liquid transport (32, 125). However, in correspondence received after this research was performed, Harper (125) described the method as using a cellulose sponge in contact with a water-filled beaker. The test fabric was placed over the beaker and in contact with the moist sponge.

One major problem with this method centers around the type of sponge used. The holes in a cellulose sponge are very irregular in size, shape, and spacing. In addition, cellulose sponges do not wick water well. The sponge could influence the transport rate. Another problem might occur in mounting the fabric over the sponge. A rubber band was used to hold the fabric in place. It was not clear whether the edges of the test specimen were sealed off to prevent moisture loss from this area.

Most moisture transport tests generally use distilled water. Rees (121) determined that the rate of vapor transport using distilled water did not differ significantly from the rate using an artificial acid perspiration solution.

A more complex apparatus is the life-sized sweating man with movable arms and legs. This apparatus would perhaps more fully replicate wear conditions than any of the other tests. However, this apparatus is prohibitive in cost for the average laboratory. Research using the sweating man should offer an insight into moisture transport of apparel systems. The copper man at the U.S. Army Natick Laboratory has been used to calculate the maximum heat transfer through clothing. Both the amount of heat transferred by conduction and evaporation can be determined.

Mecheels (14) also used a sweating man to examine ventilation of garment closures. Readings were taken with the closures open and shut, with and without movement of the arms and limbs. The environmental conditions were increased in a step-wise manner.

The units or terms used in reporting data have varied from direct units to indirect units. Direct units can express the amount of moisture transport in grams or the rate of moisture transport as grams per square meter per 24 hours. Resistance terms were discussed in relation to use with the dish method. Greenwood (9) states that the least progress has been made toward developing usable, understandable units. He addedthat units must be precise and easy to use.

The U.S. Army Natick Laboratory has used subjects to evaluate the comfort of clothing systems. The American Society of Heat, Refrigerating, and Air-Conditioning Engineers (ASHRAE) uses subjects to determine room comfort. Physiologists use subjects to determine sweat rates and heat production.

Tests using subjects can be performed in controlled environmental laboratories or in the field under actual conditions. Physical activity and environmental conditions are more controlled in the environmental chamber tests. Acclimatization of subjects may be allowed to occur before the test period starts (29, 126).

The ASHRAE environmental laboratory at Kansas State University consists of a monitoring room, control room, pre-test room, environmental test room, and shower (127).

Gilling (100) at the Shirley Institute has conducted numerous tests using subjects. He urged that proper control be used in environmental conditions, instrumentation and measurements, activity level, and subjective assessment.

Gilling (100) also stressed the use of proper research design and statistical analyses. He suggested that each subject should wear each garment and participate in all tests. For statistical analyses, Gilling suggested the use of the Latin square design. Leach (2) and Andreen et al. (128) have used "half garments" in tests using subjects, with each garment composed of two different fabrics.

Fourt and Hollies (3) urged the use of persons to determine the following: effect of body movement on evaporation, subjective preferences, water content during wear, and distribution of perspiration over the body and in the clothing.

A few researchers have tried to determine whether the same results would be obtained for physical tests in the laboratory and tests using subjects. Leach (2) did not find a correlation between the two types of testing.

Equations which attempt to predict vapor transport have been used. Many of these equations are based only on the diffusion mechanism, and may not be too accurate. Equations have also been used to convert data obtained at one set of environmental conditions to another set of environmental conditions. Mecheels (14) criticized this type of conversion.

The U.S. Army Natick Laboratory (29, 126) has begun to use computer modelling to predict comfort responses. Natick Laboratory has been performing additional tests in the laboratory on subjects and physical tests on fabrics to determine the accuracy of the computer model.

Gilling (100, 129) at the Army Personnel Research Establishment in England said that his military research was conducted in three phases. The physical properties of the fabric are evaluated in the laboratory. Comparative physiological trials using subjects wearing garments in controlled conditions are conducted. Lastly, troop trials are conducted in the field.

Environmental conditions other than standard textile test conditions of 21.1 ± 1.1°C. (70 ± 2°F.), 65 percent relative humidity, have been used for moisture transport tests. Mecheels (11) used an environmental laboratory capable of a temperature range from -30 to 50°C. (-22 to 122°F.); any relative humidity could be used. Hoffman and Peterson (79) used conditions of 32.2°C. (90°F.) and 60 percent relative humidity.

Most tests in the laboratory have been performed in ambient air. The following velocities have been used: 0.071 meters per second (130), 50 feet per minute (50), 0.8 meters per second (131), 1.3 meters per second (126), and a range of 3 to 14 miles per hour (132). No standard velocities have been established to represent a low, medium, and high velocity. Units for reporting air velocity vary greatly.

Basic Fabric Properties Tests

As reported earlier, various properties have been used as indicators of moisture transport properties of fabrics. Britt (133) said that quick indicators give data which do not allow the measurement of all transport mechanisms. It is also possible that basic fabric property tests do not apply to a variety of wearing conditions.

Researchers often use a combination of moisture transport tests and basic fabric property tests. Few researchers have examined the data from the two types of tests to determine whether any correlation exists. Often several of the basic fabric property tests are performed. In general, the basic fabric property tests are quick to perform.

Harper (125) said that the Southern Regional Research Center was currently using the following combination of tests: wicking rate, drop absorption, moisture regain, transport fabric wick, transport sponge wick, total absorption, and water vapor transport.

Moisture absorption has been used as an indicator of the fabric's total capacity to absorb moisture (7, 8, 32). This absorption was related to both the fiber content and the fabric structure; it was also influenced by finishes. Knight (7, 8) centrifuged the fabric after determination of moisture absorption. This gives the amount of moisture remaining in the fabric which was held mainly in the fiber itself.

Air permeability tests have been used as indicators of the permeability of other fluids, such as oils and water (133). A standard test method and apparatus was available for determination of air permeability.

One test for fiber wettability involves the measurement of the advancing contact angle after a drop of liquid has been applied (31, 134). This gives the wettability of the individual fiber. Another test used two fibers mounted in a "V" position; the amount of rise of the liquid is measured (135). Lichstein (136) has developed a new test, "demand wettability," to measure wetting in terms of volume or rate.

Wicking tests have been used extensively (4, 32, 98). This is one of the only fabric property tests concerned with the rise of liquids or liquid transport. However, this test is somewhat limited because it must be performed in ambient conditions. The test is based on the rise of liquid for a short time period. This test may not measure the diffusion mechanism. Both horizontal and vertical wicking tests have been used; however, the latter is used most frequently today.

The drop absorption test has also been used frequently. The test is quick to perform and requires no special apparatus. The test measures the time for a drop of water to disperse into the fabric. The American Association of Textile Chemists and Colorists (AATCC) (137) has a standard test method for resistance to wettability which is used to determine water repellent properties of fabrics. This method uses the same procedure as the drop absorption test.

The American Society for Testing and Materials Annual Book of ASTM Standards, Part 24, Textile Materials (11, 138), has standard test methods for fabric thickness, weight, and air permeability.

The most common method for determination of pore volume is by the mercury intrusion method. Newer methods include nitrogen sorption and sorption of carbon tetrachloride vapor (139). These tests are difficult to perform and require expensive equipment. Pore volume tests are not used much to study moisture transport aspects of textiles.

Lastly, Renbourn (4) suggested that today more sophisticated studies can be conducted which are capable of examining several variables simultaneously. This is possible through the use of correct research design and statistical analyses. He added that in textile research, it was often difficult or impossible to control all variables.

Chapter 3

EXPERIMENTAL RESEARCH DESIGN AND PROCEDURE

The first part of this research determined moisture transport properties of selected knit fabrics in order to examine the role of fiber content, fabric structure, moisture form, and air velocity. The researcher developed a test method which was capable of measuring vapor and liquid moisture with and without a moderate air current over the fabric. The second part of the research examined the relationship between the moisture transport test and other tests often used as quick indicators.

This chapter is divided into two major sections: (1) research design, and (2) test procedures.

RESEARCH DESIGN

Moisture Transport Tests

This portion of the research examined moisture transport properties of selected knit fabrics. Four independent variables were examined; two were fabric variables, fiber content and fabric structure, and two were treatment variables, air velocity and moisture form. The dependent variable measured was the rate of moisture transport reported in grams/meter^2/24 hours (g/m^2/24 hrs.).

Selection of test fabrics. The two major fabric variables, fiber content and fabric structure, provided the basis for the selection of test fabrics. The question concerning which fibers are more comfortable in relation to evaporative cooling resulting from moisture transport centers around whether to use a hydrophilic fiber or a hydrophobic one; blends also offer a possible solution.

Cotton was selected to represent the hydrophilic fiber, polyester to represent the hydrophobic fiber, and a 50/50 percent cotton/polyester to represent an intimate blend. These fibers represent a high volume usage in knit apparel.

The range of knit structures included in this study was somewhat limited because of the lack of availability of various types of knit constructions in all of the selected fiber contents. Weft knit structures were used for the study; a jersey and an interlock knit allowed examination of single and double knit structures. Both knit structures are widely used for apparel fabrics.

Fabrics used in this research were commercially selected at random from producers' stocks to represent the selected fiber contents and fabric structures. The fabrics used in this research are listed in Table 2. The knits of textured filament polyester had been heat set to insure

Table 2

Test Fabrics

Fiber Content	Fabric Structure	Finish
100% cotton	Jersey	Permathol (DMDHEU)*
	Interlock	Permathol (DMDHEU)
50/50% cotton/ polyester	Jersey	Permathol (DMDHEU)
	Interlock	Permathol (DMDHEU)
100% polyester	Jersey	Heat set
	Interlock	Heat set

*DMDHEU is dimethyloldihydroxyethyleneurea.

dimensional stability. The cotton/polyester and cotton fabrics had a shrinkage control resin finish. It is essential for maintenance of dimensional stability in knits containing cotton.

It was not possible to control all fabric variables. Several fabric properties were influenced by the fiber content and/or fabric structure. The basic fabric properties were measured and reported.

Treatment selection. The two treatment variables examined in this research were moisture form and air velocity. Moisture varies in wear situations from vapor to liquid form. Therefore, it was desirable to measure moisture transport properties using (1) vapor form to replicate insensible perspiration under normal conditions, and (2) liquid form to replicate sensible perspiration or sweat during more severe conditions.

Air currents occur during wear whenever the body and/or the air is in motion. Many tests reviewed were performed only in ambient air, thus ignoring the role of convection currents on evaporative cooling. The researcher performed moisture transport tests, both vapor and liquid forms, with both ambient air and with moderate air currents over the fabric's upper surface.

The following series of tests were performed on each of the six test fabrics:

1. Vapor form/ambient air
2. Vapor form/moderate current
3. Liquid form/ambient air
4. Liquid form/moderate current.

The temperature and relative humidity were controlled at 37°C. (98.6°F.), 30 percent r.h. to replicate conditions in a hot, dry environment.

Hypotheses. The major research hypotheses related to the major independent variables are the following:

H_1: No significant differences will exist in the ability of various fibers, 100 percent cotton, 100 percent polyester, and 50/50 percent cotton/polyester, to transport moisture.

H_2: The jersey knit will allow more moisture transport than the interlock knit structure.

H_3: The knit fabric structure will be a more important fabric variable in moisture transport than fiber content.

H_4: Liquid test methods will transport more moisture than vapor test methods.

H_5: Increases in rate of moisture transport will result from increases in air velocity.

Statistical analysis. The statistical analysis used for this part of the research was a four-way analysis of variance which allowed examination of each independent variable and all possible combinations of these variables. The analysis of variance was done using BMD-02V analysis of variance program (140) on a Control Data Corporation 3150 computer.

Using the results from the statistical analysis, the null hypotheses were found to be either true or false. The research hypotheses were then examined and either accepted or rejected.

When an independent variable has just two levels, a statistical significant difference implied that level one differs from level two. But if a statistical significant difference was shown when an independent variable had three or more levels, it does not necessarily imply that differences exist at all levels. In order to determine where the significant differences occurred, a post-hoc statistical test should be performed. In this research, if a significant difference was obtained for fiber content, the only variable containing over two levels, a Newman-Keuls post-hoc statistical analysis (141) was performed.

Correlation

The second part of the research examined the relationship of test results from part one, the moisture transport test series, to other tests used as quick indicators.

This was done to determine whether any of the quick indicators were capable of giving results similar to any of the tests in the test series. The tests in the series were designed to replicate various conditions of wear, including moisture form and air velocity. It was possible for all mechanisms of transport to occur in the test series. Some criticism of the quick indicators suggests that they do not measure all mechanisms which can occur. This suggests that they might not give the same type of results as those obtained from various tests in the test series.

If a series of quick indicators or a single indicator could be found which gave results similar to those in the test series, testing time could perhaps be reduced. Such a simplification would, it is hoped, encourage more manufacturers to determine moisture transport properties of apparel fabrics.

The correlation test also determined whether any correlations existed among any of the tests in the series. If similar results were obtained on any of the tests, perhaps the number of tests in the series could be reduced and the testing simplified.

Quick indicators. Tests used as quick indicators in this research were the following: fabric thickness, fabric weight, air permeability, percent fabric moisture regain, percent moisture regain during static absorption, percent moisture imbibition after centrifugation, vertical wicking in the warp and filling directions, and evaluation of wettability for the face and back sides of the fabric.

Some of these tests are basic fabric properties, whereas others measure basic moisture properties.

Statistical analysis. For this section, the statistical analysis used was Spearman's rho, as determined by using Application Rho-Tau computer program on a Control Data Corporation 3150 computer.

Assumptions and Limitations

Assumptions.

1. A valid method for determining the rate of moisture transport for both vapor and liquid moisture forms can be established.
2. Distilled water will not produce results significantly different from perspiration.
3. Finishes which react with the fiber were considered to be a fiber variable.
4. Other variations in fabric properties often resulted from the fiber content and/or fabric structure.

Limitations.

1. This research determined only the rate of transport; it did not examine other thermal or non-thermal factors associated with moisture transport or general clothing comfort.
2. This research examined fabric and treatment variables; it did not examine variables related to the

garment's style or fit or bellows ventilation.

3. The test method could not replicate all environmental conditions which could occur during wear; this research examined variations in moisture form and air velocity at a controlled temperature and humidity.

4. This research examined only the rate of moisture transport; it did not attempt to identify and quantitatively measure each transport mechanism.

5. The number of knit fabric structures which were examined was limited by the availability of other knit structures in all the selected fiber contents.

TEST PROCEDURES

Test Specimen Preparation

The following steps were performed before physical testing was started: (1) identification of fiber content and fabric structure, (2) scour fabric, (3) develop sampling plan, (4) cut specimens, and (5) condition specimens.

After positive identifications for fiber content and fabric structure were obtained, preparation of test fabrics continued.

Scouring was necessary (1) to remove non-durable finishes and knitting oils, and (2) to allow the fabric structure to stabilize. Both factors could influence moisture transport rate.

The scour was performed according to AATCC 135 1973-IB for determining changes in dimensional stability. The dimensional stability test areas were selected at random and marked. Tubular fabrics remained in this state during the scour. The fabrics were washed three times in an automatic washer using twelve-minute cycles. The water temperature was 41 ± 3^{o}C. (105 ± 5^{o}F.). Dash detergent was used. The samples were tumble dried, then spread flat to measure changes in dimensional stability and the wale count.

The sampling plan was developed around the narrowest fabric whose measurement between its folded edges was 76.2 cm. (30"). After the fabrics were spread or cut and spread, 10 percent was eliminated from the outer and upper edges and from each side of the center fold. The sampling plan is shown in Appendix A.

Enough fabric was available to develop the sampling plan using a random coin toss. Specimens were obtained from widely differing wales and courses. Three specimens for each test were used. The fabric specimens were cut by hand.

It was not necessary to code each fabric since fabric direction was evident. Test data were recorded by the fabric's color to prevent researcher bias.

Specimens were allowed to reach equilibrium in the specified conditions before testing started. All moisture tests were performed at 37°C. (98.6°F.), 30 percent to replicate conditions in a hot, dry climate. It was necessary to perform other basic fabric tests at standard textile testing conditions 21.1 ± 1.1°C. (70 ± 2°F.), 65 percent r.h. since the large pieces of testing equipment could not be moved to the hot laboratory.

List of Tests Performed

In accordance with the research design, the following tests were performed on the six test fabrics:

Basic fabric properties.

1. Fiber identification
2. Identification of fabric structure
3. Fiber length
4. Yarn number--ASTM D1059-72
5. Yarn twist--ASTM D1423-71
6. Yarn construction--ASTM D1244-69
7. Wales per unit--ASTM D231-62
8. Dimensional changes--AATCC 135-1973 IB
9. Fabric thickness--ASTM D1777-64
10. Fabric weight--ASTM D1910-64
11. Air permeability--ASTM D737-69
12. Percent moisture regain--ASTM D2654-71
13. Percent moisture regain after static absorption--AATCC 21-1972 modification
14. Moisture imbibition after centrifugation.

Moisture transport properties.

1. Moisture Transport Test Series
    a. Vapor Form/Ambient Air
    b. Vapor Form/Moderate Air Current
    c. Liquid Form/Ambient Air
    d. Liquid Form/Moderate Air Currents
2. Vertical Wicking Test
    a. Warp Direction
    b. Filling Direction
    c. Bias Direction
3. Evaluation of Wettability--AATCC 39-1971 modification
    a. Face
    b. Back.

The above tests were performed in a random order; the sequence for testing fabrics was also randomly chosen. The fabric and test sequence is given in Appendix B.

Standard test methods were used whenever available and/or appropriate; a brief description which includes apparatus used and/or any modifications in procedure follows. A complete description is given when no standard test method existed.

The units used to report data were the recommended S.I. units (142), followed by U.S. customary units within parentheses.

Moisture Transport Test Method

Development. No standard test method has been adopted in the United States for moisture transport; Canada does have a standard test method for vapor transport (10). Test apparatus and methods were reviewed in Chapter 2. No test methods were found that were completely satisfactory.

The main objections included the inability of tests to (1) measure liquid transport, (2) measure all transport mechanisms, and (3) maintain a constant distance between the test specimen and the water level. Some equipment was too expensive and complex.

Criteria used for developing the test apparatus and methods follow. Separate tests for determination of vapor and liquid transport, each to be performed with ambient air and a moderate air current over the fabric's upper surface, were desired. This suggested the use of a series of tests to better replicate use conditions than could just performing a vapor test in ambient air.

Use of the same basic apparatus, with only slight modifications, for the liquid and vapor tests would simplify testing. It was also necessary that the method be capable of measuring all moisture transport mechanisms. The test method should not take an excessively long time to perform, and it should not be too complex to perform or interpret. A test series which was relatively quick and easy to perform and which was indicative of use conditions was desirable.

The water level was to remain constant throughout the test period. This was a necessity, especially in the case of liquid transport where the sample was to remain in contact with a moist surface. Most tests for determining moisture transport rate or resistance were based on either a volumetric or a gravimetric principle. In the gravimetric vapor tests, the distance between the test specimen and the water level changed as evaporation occurred. Rees (143) in 1945 used a volumetric method for determining vapor transport. This apparatus was modified for use in the test series in this research. The entire test method follows.

Purpose and scope. The purpose of this test was to determine moisture transport rate of apparel fabrics for vapor and liquid moisture forms using a moderate air current and ambient air over the fabric's upper surface. This research used a single thickness of fabric.

Principle. The test method used a vessel filled with water which was attached by tubing to a capillary tube. The capillary tube was at the same level as the water in the vessel. The test specimen was mounted in a holder and positioned over the vessel. As evaporation occurred from the water level in the vessel, the water supply in the capillary tube maintained a constant water level in the easy to perform and which was indicative of use conditions was desirable.

The water level was to remain constant throughout the test period. This was a necessity, especially in the case of liquid transport where the sample was to remain in contact with a moist surface. Most tests for determining moisture transport rate or resistance were based on either a volumetric or a gravimetric principle. In the gravimetric vapor tests, the distance between the test specimen and the water level changed as evaporation occurred. Rees (143) in 1945 used a volumetric method for determining vapor transport. This apparatus was modified for use in the test series in this research. The entire test method follows.

Purpose and scope. The purpose of this test was to determine moisture transport rate of apparel fabrics for vapor and liquid moisture forms using a moderate air current and ambient air over the fabric's upper surface. This research used a single thickness of fabric.

Principle. The test method used a vessel filled with water which was attached by tubing to a capillary tube. The capillary tube was at the same level as the water in the vessel. The test specimen was mounted in a holder and positioned over the vessel. As evaporation occurred from the water level in the vessel, the water supply in the capillary tube maintained a constant water level in the vessel. The amount of water loss in the capillary tube was measured after a three-hour period. The rate of transport was calculated in grams/meter^2/24 hours.

A modification in specimen mounting was necessary to change from vapor to liquid transport. For vapor transport, the test specimen was mounted 1.5 cm. above the water level. Liquid transport was determined with the specimen in contact with a moist wicking sponge. The other side of the sponge was in constant contact with the water supply from the vessel. Moderate air currents were created by a fan.

Apparatus. A diagram showing the assembly of test apparatus is shown in Figure 1. Diagrams of the specimen holder and assemblages for vapor and liquid forms are shown in Figures 2, 3, and 4. A diagram showing the use of a fan to create air currents is shown in Figure 5. The apparatus needed for the test included the following:

Glass vessel--thick walled Pyrex glass vessel with inlet formed near the bottom of the vessel; outer diameter 10.2 cm. (4"), inner diameter 8.84 cm. (3 1/2"), height 7.5 cm. (2 7/8").

Capillary tube--tube attached perpendicularly to glass tubing, a thistle tube reservoir and a stopcock were above; the capillary tube was 0.1 ml. in 0.01 ml., the glassware was assembled by a glassblower.

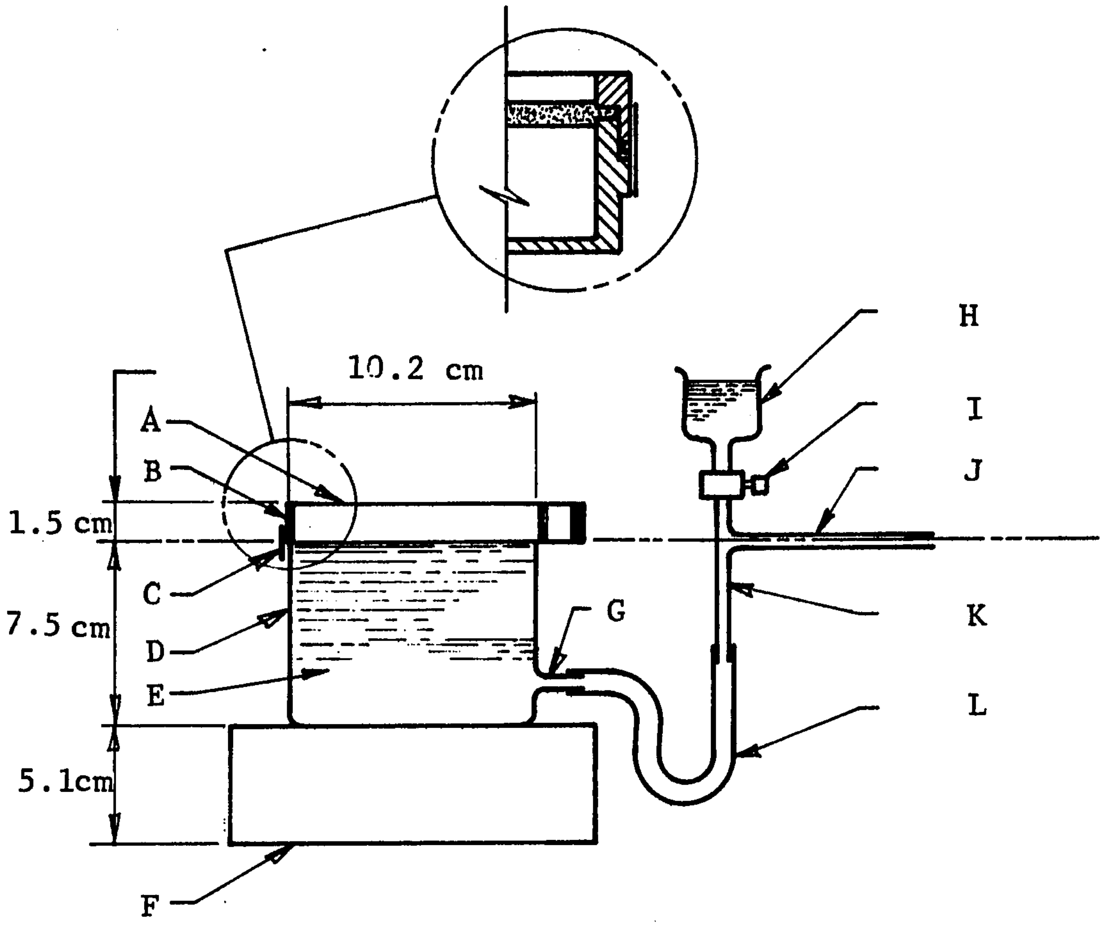


Fig. 1. Diagram of Moisture Transport Test Apparatus

A--Fabric Specimen
B--Specimen Holder
C--Tape, Water Impermeable
D--Vessel
E--Distilled Water
F--Block

G--Inlet Tube
H--Reservoir (Thistle Tube)
I--Stopcock
J--Capillary Tube (0.1 ml in 0.01 ml)
K--Glass Tubing
L--Clear Tygon Tubing

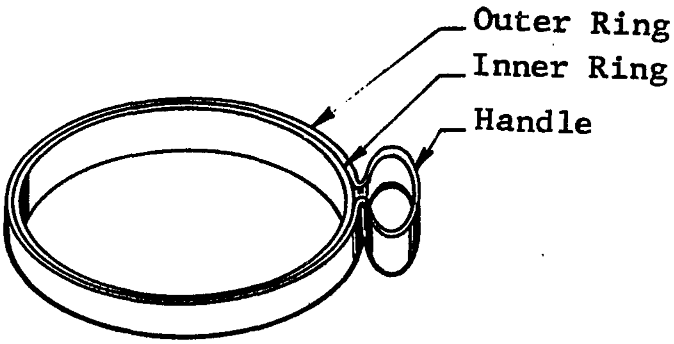
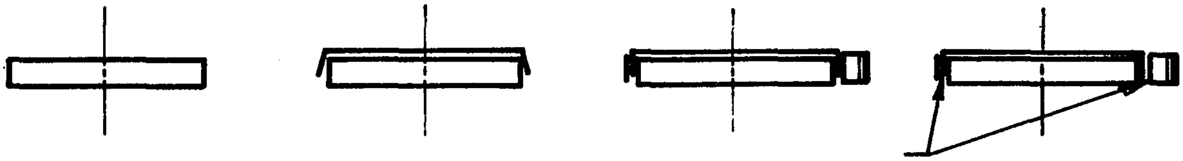


Fig. 2. Specimen Holder for Moisture Transport Tests
(Top View)



a. Inner ring

b. Fabric over ring

c. Add outer ring

d. Wax areas marked

Fig. 3. Specimen Mount: Procedure I--Vapor Transport
(Side View)

a. Inner ring, mesh support at bottom (top view)

b. Insert wicking foam

c. Fabric over assembly

d. Add outer ring and wax

(side view)

Fig. 4. Specimen Mount: Procedure II--Liquid Transport

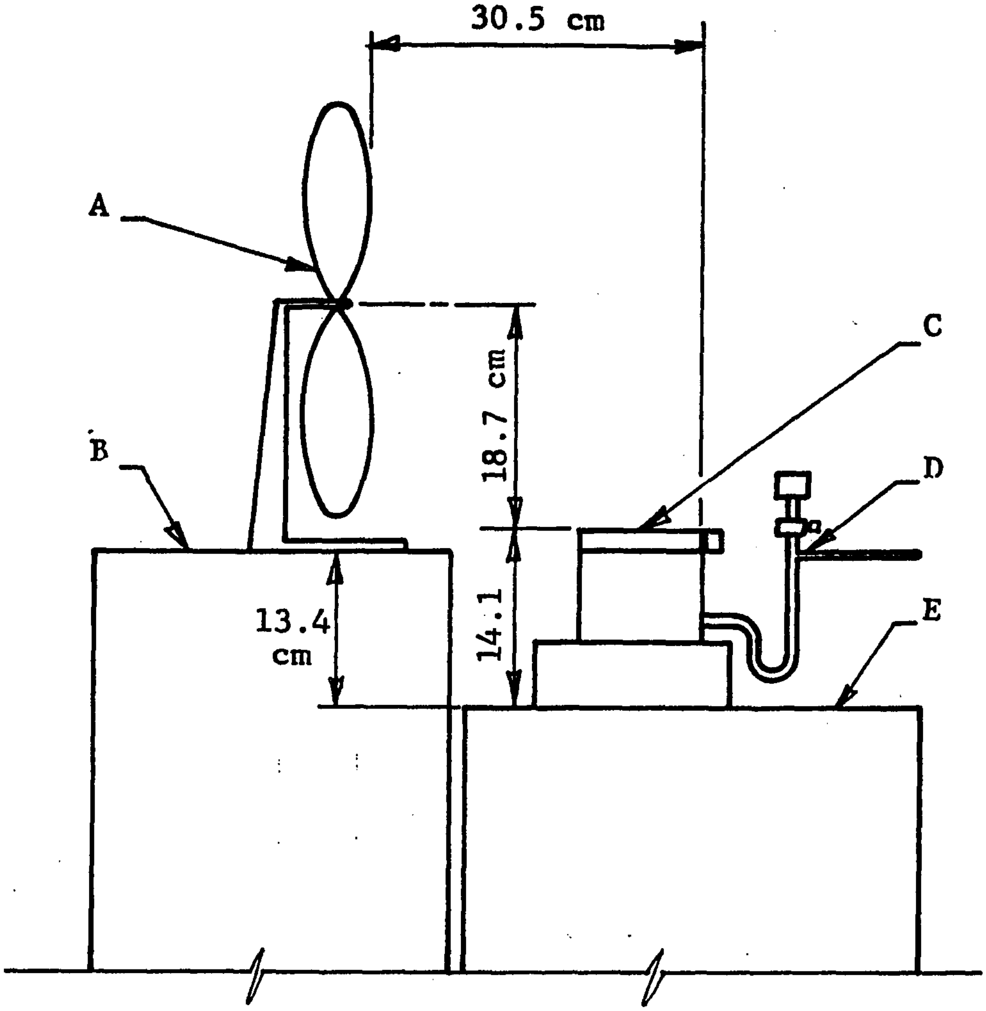


Fig. 5. Diagram of Apparatus for Moisture Transport Test Modification B--Moderate Air Currents

A--Fan, 3-bladed

B--Cart

C--Fabric specimen

D--Moisture Transport Test Apparatus

E--Table

Tubing--clear Tygon tubing to connect vessel inlet to capillary tube assembly; this tubing prevents deposit formation.

Ring stand.

Burette holder.

Block--styrofoam block 5.1 cm. (2") to elevate vessels.

Ruler--small, clear ruler with S.I. units to measure the amount of water loss in the capillary tube since the markings on the tube were too far apart for accuracy.

Specimen holders--clear plastic embroidery hoops, outer diameter 10.2 cm. (4") (see Figures 2, 3, and 4).

Tape--water impermeable electrical tape.

Foam--wicking cellular polyurethane foam--Acquell from Scott was used in the specimen holder for the liquid specimen holder (see Figure 4). Product specifications include: absorbs 30 times its weight of liquid, 70 pores per linear inch, density of 2 lbs./cu. ft. (144).

Pen--suitable for marking on glass surface.

Fan--three-bladed fan used in stationary position, low speed to create moderate air.

Anemometer--Cenco anemometer to determine the air velocity of the fan.

Table and cart.

Distilled water--at test room temperature.

Plastic discs--clear discs the same size as outer diameter of vessel.

Clock.

Wax in pan--paraffin in a pan larger than the specimen holders.

Small paint brush.

Tissues--Kimwipes.

Specimens. Each test in the series used three specimens. These specimens were from widely differing wales and courses. The sample size of approximately 11 cm. (4 1/3") in diameter prevented the mounted specimen from extending over the bottom edge of the holder. The specimen's test area was 0.268 m^2.

The specimens, wrinkle-free and undistorted, were conditioned at 37^{o}C. (98.6^{o}F.), 30 percent r.h. until equilibrium was attained.

General procedure. The preparation procedure was used for each test in the series. The general preparation is discussed first, followed by Procedure I for determination of vapor transport, Procedure II for determination of liquid transport, Modification A ambient air, and Modification B moderate air current.

Preparation procedure. The glassware was cleaned with distilled water. The apparatus was assembled as shown in the diagram in Figure 1.

The vessel was filled with distilled water. The water supply should feed into the capillary tube and continue up into the thistle tube. The stopcock which was open during the fill period was closed when filling was completed. All air bubbles were removed.

The water line of the vessel should be even with the top edge of the vessel. To determine when it was even, the clear plastic disc was placed over the mouth of the vessel. If it was not full, air could be seen between the disc and the water. If excess water was in the vessel, it overflowed until the correct level was obtained.

The capillary tube was adjusted by raising or lowering the burette holder, so that the capillary tube was level with the water line of the vessel. The water level in the capillary tube was filled between 0.08 and 0.10 ml. to prevent the water from extending to the end of the tube. The end of the capillary tube was wiped with tissue to remove any water.

The water loss from the capillary tube was observed to determine whether the rate of flow was steady. If the rate was not steady, additional adjustment of the height of the capillary was made. The ring stand was marked with tape when a steady flow was obtained to note the correct position of the clamp of the burette holder.

<u>Procedure I--vapor transport</u>. The preparation procedures were followed. The procedure shown in Figure 3

was followed to mount test specimens in the holder. A conditioned specimen was placed over the small, inner ring of the specimen holder. Only the outer edges of the test specimen were held so as not to touch or distort the test area. Very little pressure was applied to the test specimen to avoid stretching and distorting it. The large, outer ring of the specimen holder was placed over the specimen.

The specimen holder was dipped into the pan of hot wax to seal the lower edges. The edge near the handle was painted with wax. Care was used to prevent getting wax in the test area.

The specimen mount was placed over the top edge of the vessel. The outer edges of the holder and vessel were even. The wax was pliable and adhered to the vessel's upper edge. The specimen holder was taped to the vessel to prevent any possible moisture loss at this point and to firmly secure the specimen holder in place.

The lowest point of the meniscus in the capillary tube was marked; the test started. At the end of the three-hour test period, the lowest point of the meniscus was recorded. The lowering of the meniscus in the capillary indicated the loss of water from the vessel. This was later converted to rate of transport in grams/centimeter^2/24 hours.

The test specimen holder was removed and cleaned. The capillary tube was refilled by opening the stopcock, thus allowing water to enter from the above reservoir.

Procedure II--liquid transport. The preparation procedures were followed. The procedure shown in Figure 4 was followed to mount test specimens in the holder. The specimen holder for the liquid test was modified by attaching a mesh screen to the bottom of the inner ring. A precut piece of the wicking polyurethane foam was inserted into the smaller ring; it was supported by the mesh screen. The foam was wet out in 30 ml. of water and allowed to drain.

The fabric specimen was placed gently over the sponge to avoid the application of excess pressure which could cause premature wetting of the test specimen. The large, outer ring was placed over the assembly. The small area near the handle was waxed to prevent moisture loss at this point.

The specimen assembly was placed over the vessel, centered, and taped to secure in place and prevent edge loss. The test period started. At the end of the test, the distance the water in the capillary tube had travelled was marked and measured. This was later converted to rate of transport.

The test specimen holder was removed, disassembled, and cleaned. The capillary tube was refilled by opening the stopcock, thus allowing water to enter from the above reservoir.

Modification A--ambient air. The apparatus was assembled for this test, as shown in Figure 1. This modification was performed in conjunction with Procedure I, vapor transport, and Procedure II, liquid transport. The tests were performed in a draft-free conditioning room.

Modification B--moderate air currents. The basic apparatus was assembled, as shown in Figure 3. This modification was performed in conjunction with Procedure I, vapor transport, and Procedure II, liquid transport.

A fan was placed on a higher cart to provide air currents over the fabric's upper surface (see Figure 4). The fan was set at the low speed. The anemometer recorded the air velocity at the specimen level as 29.4 km/hr (2410 ft/min or 47.4 mph).

Calculations. Obtain a mean for each test performed for each fabric. To calculate the rate of transport, the following formula was used:

$$\begin{array}{l}\text{Transport Rate} \\ (\text{grams/meter}^2/24 \text{ hours})\end{array} = \underline{x} \text{ mm.} \times 0.031$$

$\underline{x}$ mm. = distance water travelled in capillary tube during test period.

In this research, the computer performed this calculation.

Report. The report should specify the following: test procedure and modification used, temperature and relative humidity, test specimens, and transport rate ($g/m^2/24$ hr.).

Developmental trials. Several tests were performed during the development of the test series. A test was performed to determine whether there were any leaks in the system. An impermeable plastic fabric was mounted in the specimen holder. No moisture escaped during the 24-hour test period. Therefore, it was only possible for moisture to leave the system through the fabric. This test was performed on both sets of test apparatuses used in this research.

Various time periods were tried to determine the shortest period which could give accurate results. The following time periods were tried: 24, 12, 5, 4, 3, and 1 hours. The three-hour period was used since it allowed greater accuracy than the one-hour period. Longer test periods were unsuitable for some specimens because all of the water in the capillary tube was gone, and an accurate reading could not be obtained. Little moisture transport occurred for some tests and fabrics, so a one-hour period was unsuitable. However, nothing appeared to be gained by using a test period over three hours.

Evaluation of Wettability

AATCC Test Method 39-1967 was used with the modifications described. This method is also called drop absorption.

Apparatus. For a diagram showing the assembly of apparatus, see Figure 6. The apparatuses needed for the test included:

Ring stands.

Burette holder.

Pipette--2.54 cm. (1") in 1/10 ml., capable of delivering 15-25 drops of water per ml.

Stop watch.

Magnifying glass.

Ruler.

Scissors.

Tissues--Kimwipes.

Paper towels.

Distilled water--at room temperature.

Specimens. The specimens used for this test were 11 cm. (4 1/3") in diameter. The specimens were previously used in the vapor transport test. The samples had not come in contact with liquid and had not been contaminated. The specimens were allowed to return to 37°C. (98.6°F.), 30 percent r.h. Three specimens were tested with the face up and three with the back side facing upward.

Procedure. The test apparatus was assembled, as shown in Figure 6. The specimen holder as used in the liquid transport test was placed on the ring stand (see Figure 4). The mesh side of the holder was facing upward to obtain the 2 cm. distance from the tip of the pipette.

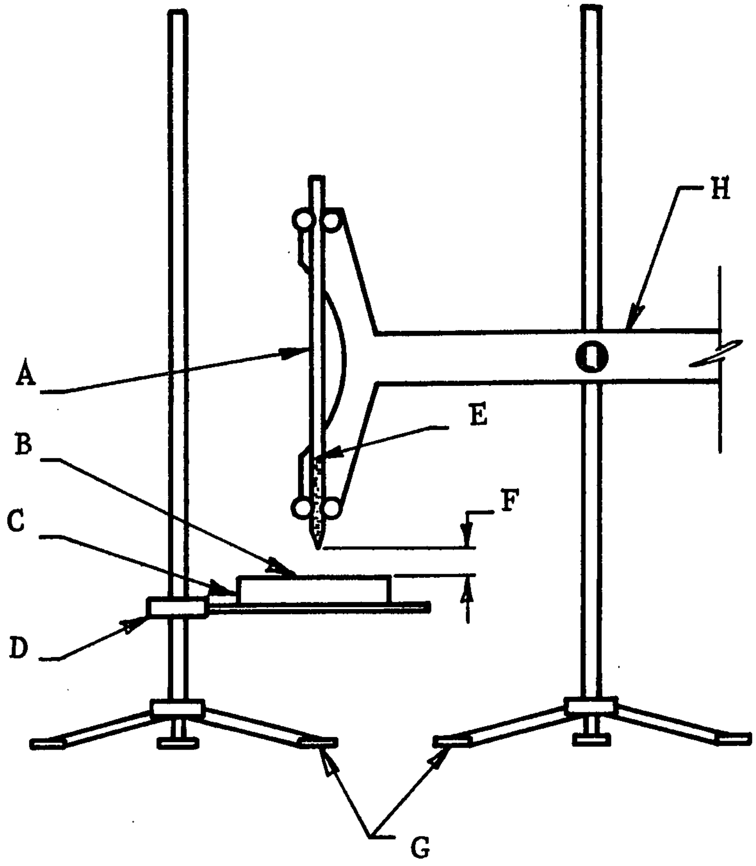


Fig. 6. Diagram of Drop Absorption Test Apparatus

A--Pipette
B--Fabric specimen
C--Specimen holder
D--Ring holder

E--Distilled water
F--2 cm distance
G--Ring stands
H--Burette holder

Additional equipment needed for this test included a stopwatch and a beaker of distilled water.

The test specimen was inserted in the specimen holder and placed face up on the ring stand.

The pipette in the burette holder was filled with a small amount of distilled water. The tip of the pipette was wiped with a tissue. The top of the pipette was covered by a finger to prevent the water from flowing. The stop watch was started as the water drop hit the fabric.

The following was observed and recorded: (1) time for initial penetration, (2) time for complete wetting, and (3) size and shape of wetted area. By using a magnifying glass, it was possible to observe the point that initial penetration occurred. The time range for initial penetration can vary from a second to several minutes. Instantaneous spreading of the drop was recorded as one second.

It was more difficult to determine when complete penetration or wetting had occurred. This reading was taken after all the water from the drop had spread out completely leaving no water film or reservoir. After the test was completed, the area wetted during the test period was marked. This served to give more information regarding the water's path and to indicate whether moisture travel was mainly along the wales or courses in the knit.

Vertical Wicking Test Procedure

No standard wicking test method has been adopted for textiles. Several variations of the vertical wicking test have been used as an indicator of a fabric's ability to absorb and transport moisture (145, 146). The procedure used in this research introduced some modifications; therefore, the entire procedure follows.

Purpose and principle. The purpose of this test was to determine the distance water traveled up the test specimen when the bottom edge remained in a water reservoir. The specimen was suspended vertically. Various time periods can be used for the test; this research used one and five minutes. The test was used as an indicator of a fabric's ability to transport moisture away from the skin.

Apparatus. For a diagram showing how the test apparatus was assembled, see Figure 7. The apparatus needed for the test included the following:

Ring stand.

Rod.

C clamp.

Glass vessel--suitable for maintaining a water level of 2 cm.

Weight--a safety pin was used because it was easier to attach than a paper clip which is generally used.

Stop watch.

Ruler.

Distilled water--room temperature.

Fabric stain--T.I.S. #2 stain.

Scissors.

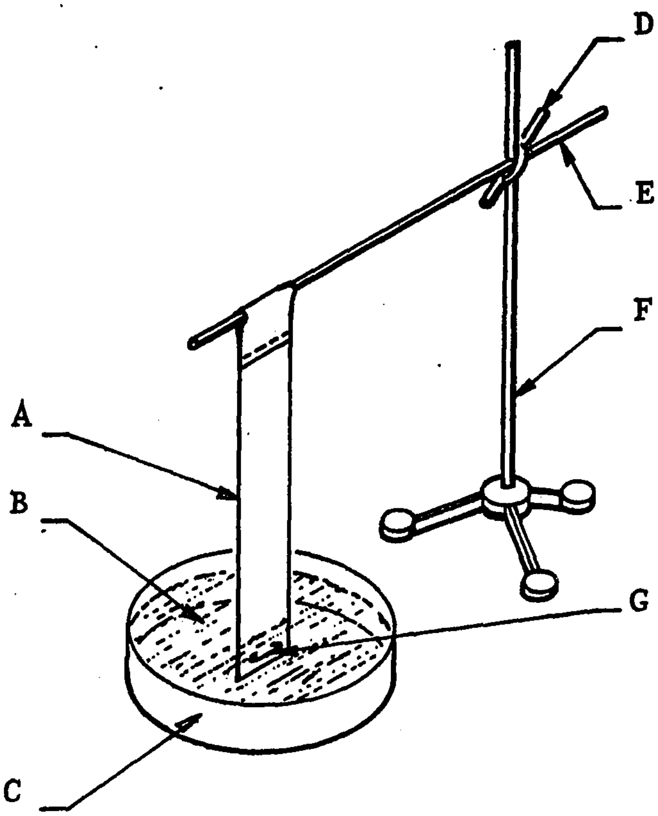


Fig. 7. Diagram of Vertical Wicking Test Apparatus

A--Fabric specimen (3 x 22.5 cm)
B--Distilled water, 2 cm height, T.I.S. #2 stain added
C--Vessel
D--C clamp
E--Rod
F--Ring stand
G--Safety pin used as a weight

Additional equipment needed for this test included a magnifying glass, ruler, scissors, and a stopwatch.

Specimens. Three specimens 25.5 cm. by 3 cm. were cut from the warp, weft, and bias directions. The bias strip test was added because it showed more about whether the water wicked along the wales or courses than tests performed in either the warp or weft directions.

The top of the specimen was folded back and sewn a specified distance. This provided for ease of mounting the specimen over the rod. The specimens were continuously fed into the sewing machine so that all of the specimens were joined together. This provided for ease in handling a large number of small specimens.

Procedure. The apparatus was assembled, as shown in Figure 7. The weight was attached to the lower portion of the specimen, about 10 mm. from the bottom edge. It did not hang lower than the edge of the test specimen.

The looped upper portion of the specimen was placed over the rod. The rod was adjusted until the specimen just met the bottom of the vessel. The specimen was removed.

The vessel was filled with distilled water until a height of 2 cm. was reached. It was necessary to check and refill the water level during the test. The T.I.S. #2 stain was added and stirred.

The specimen was placed over the rod. The face and back side of each fabric was alternated to allow observation from both sides.

The stop watch was started as the specimen entered the water. The rise of the liquid was observed more closely by using a magnifying glass.

After one minute, a small clip was made on the edge of the specimen to mark the point where the highest rise had occurred. This technique was thought to be more accurate than trying to quickly measure the height of transport during the test.

The total test period was five minutes. The specimen was again clipped at the end of the test. The specimen was removed and placed flat on blotter paper. Wicking distances were recorded and averaged. The water level, 2 cm. or 20 mm., was subtracted from the average to give the total distance transported.

Percent Moisture Regain after Static Absorption

This test was performed in conjunction with the test to determine the amount of moisture retained after centrifugation. Modifications were made in AATCC Method 21-1972 Water Repellency: Static Absorption Test. The AATCC test was designated to measure the amount of resistance a fabric offers to wetting by water; it was mainly used for water repellent fabrics. The entire test procedure used in this research follows.

Purpose. This test was used as an indicator of the ease of wetting and the amount of water a fabric can absorb during static immersion in water. This could be important in the pickup of perspiration from the skin.

Principle. Five specimens were immersed in distilled water and allowed to remain in a static condition for twenty minutes. They were drained and reweighed. The percent moisture regain was calculated.

Apparatus. The apparatus needed for the test included:

Beaker.
Distilled water--at room temperature.
Stop watch.
Balance--Mettler H20, accurate to five decimal points.
Blotting paper.
Weighing bottles.
Ring stand.
Weight--20 grams.
Specimen holder--made from a large paper clip, the two looped ends were spread open until the loops were in opposite directions.

Specimens. Five specimens 5.1 cm. x 5.1 cm. (2" x 2") were tested simultaneously. The specimens were brought to equilibrium at 37°C. (98.6°F.), 30 percent r.h.

Procedure. The bone dry weight was determined previously. The five specimens were sewn together by hand and reweighed. The samples were returned to equilibrium conditions.

The apparatus was assembled. All test specimens were hooked together on the paper clip so that they hung from the same looped end of the clip. The 20 gr. weight was placed in the other looped end.

The specimens were immersed in the beaker containing distilled water for 20 minutes. The weight at the bottom of the beaker held the fabrics in a static position in the water. After they were removed from the water, they were hung from a rod on a ring stand and drained for 25 seconds. The specimens for each test fabric were placed in a weighing bottle and reweighed.

The percent moisture regain after static immersion in water was calculated using the following formula:

$$\text{Percent Moisture Regain after static immersion} = \frac{W_1 - W_2}{W_2} \times 100$$

W_1 = weight bone dry

W_2 = weight after static immersion.

Moisture Imbibition after Centrifugation

No standard test method was available for this test. Knight (7) used a similar test in a knit study. This test was performed immediately after weighing the samples in the test to determine moisture regain after static immersion.

Purpose. The test was to determine the amount of water remaining in the fabric after centrifugation. This test has been used to indicate the amount of moisture retained in the fiber since almost all of the moisture in the fabric structure is removed.

Principle. The specimen was immersed in distilled water, then placed in a commercial laundry centrifuge. The percent water remaining was calculated.

Apparatus. The following apparatus was needed for this test:

Weighing bottles.

Balance--Mettler H20, accurate to five decimal points.

Stop watch.

Centrifuge--Bock Centrifugal Extractor 24.

Specimens. The five specimens 5.1 cm. x 5.1 cm. (2" x 2") were tested simultaneously.

Procedure. The static absorption test was performed. The specimens were centrifuged for one minute; the thread loop held the specimens together. The specimens were reweighed. The percent moisture retention after centrifugation was determined using the following formula:

$$\text{Percent Moisture Retention after centrifugation} = \frac{W_2 - W_1}{W_1} \times 100$$

W_1 = weight bone dry

W_2 = weight after centrifugation.

Yarn Number

ASTM D1059-72 Yarn Number Based on Short-Length Specimens was followed. A universal yarn number balance was used to determine the yarn number which was reported in texture and denier.

Fiber Length

The fiber length was determined by using a black velvet covered board and dissecting needle as mentioned in ASTM D1059-72.

Yarn Twist

Twist in Yarns by the Direct-Counting Method ASTM D1423-71 was used. The direction of twist, number of plies, and yarn twist were determined.

Designation of Yarn Construction

ASTM D1244-69 offers a sequence with abbreviations for describing yarn construction characteristics in a concise form instead of reporting each aspect separately.

Wale Count

ASTM D231-62 (Reapproved 1970) Standard Methods of Testing and Tolerances for Knit Goods described procedure for determining the number of wales per unit area. The Alfred Suter pick counter was used. The wale count was taken before and after the fabric was scoured.

Thickness

ASTM D177-64 (Reapproved 1970) Thickness of Textile Materials was followed. A Custom Scientific Instruments C and R thickness gauge CS 55 119 was used. A 28.6 mm. (1.129 inch) circular pressure foot was used to apply pressure to the fabric in the range of 0.03 to 10 pounds per square inch (2.1-700 grams per square centimeter) as suggested in Table 1 of the test method.

Weight

ASTM D1910-64 (Reapproved 1970) Construction Characteristics of Woven Fabrics provided test procedure and conversion formulas. Five specimens 5.1 cm. x 5.1 cm. (2" x 2") were used.

Air Permeability

ASTM D737-69 Air Permeability of Textile Fabrics was used to determine air flow through the fabric. Air Flow Tested Model 9025 bench top model from U.S. Testing Company was used. See Figure 8 for a diagram.

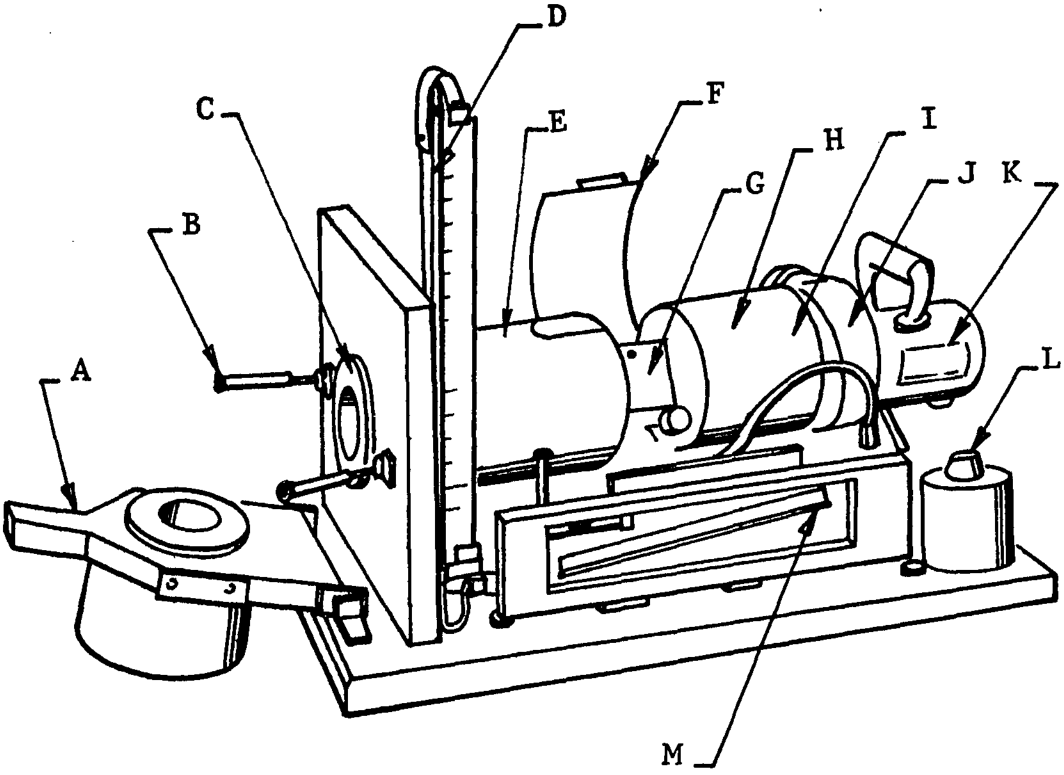


Fig. 8. Diagram of Air Flow Tester*

A--Hinged door, with orifice
B--Spring loaded hinged fasteners
C--Orifice, specimen is placed over this area
D--Vertical manometer
E--Chamber A
F--Hinged door

G--Orifice
H--Chamber B
I--Air baffles
J--Air discharge
K--Suction fan
L--Inclined manometer
M--Variable autotransformer

Additional equipment included: various size orifice, rings to hold specimen in place, calibration plates, and wrench for attaching office.

*Model 9025, U.S. Testing Co., Inc., Hoboken, N.J.

Air was drawn through the test area of the fabric specimen by means of a suction fan. The difference in air pressure at the two sides of the specimen was determined. The rate of air flow was obtained by directly reading the vertical manometer after the inclined manometer attained a reading of 0.5" (12.7 cm.). This reading was converted to an air flow measurement in $\text{feet}^3/\text{feet}^2/\text{min.}$ by checking the accompanying tables. The reading was converted to the recommended S.I. units $\text{cm.}^3/\text{cm.}^2/\text{sec.}$ by multiplying the U.S. customary units by 0.508.

Dimensional Stability and Scouring

Dimensional changes in Automatic Home Laundering of Durable Press Woven or Knit Fabrics AATCC 135-1973 IB was used. The purpose was to determine the percent shrinkage and to also scour the fabrics in preparation for testing. Three 45.72 cm. x 45.72 cm. (18" x 18") test areas were randomly selected. The specimens were not cut from the fabric. Tubular fabrics remained in this state during the test. See sampling plan in the Appendix.

Each fabric was washed three times at $41 \pm 3^{\circ}\text{C.}$ ($105 \pm 5^{\circ}\text{F.}$) as designated by Procedure I, then tumble dried as designated by Procedure B. Dash detergent was used. A Whirlpool automatic washer and dryer were used.

The fabrics were placed flat on a table upon removal from the dryer. This procedure was designed for fabrics which require no pressing after removal from the dryer.

Moisture Regain

ASTM D2654-67T Amount of Moisture in Textile Materials option one which used the oven-drying procedure at 105°C. (253°F.) was followed. Five specimens 5.1 cm. x 5.1 cm. (2") square were used. A National Appliance Oven 5510 and a Mettler Balance H20, accurate to five decimal places, were used.

Chapter 4

PRESENTATION OF DATA AND RESULTS

The main objective of this research was to examine moisture transport properties of selected knit fabrics. Physiological aspects of moisture transport are related to evaporative cooling, maintenance of body temperature, and thermal clothing comfort.

A series of four moisture transport tests were developed to replicate use conditions since no standard moisture transport test methods were available. The use conditions replicated included variations in (1) moisture form, vapor and liquid, and (2) air currents, ambient and moderate air currents.

The moisture transport test series was used in the first part of the research to examine two major fabric variables, fiber content and fabric structure, and two treatment variables, air velocity and moisture form. The test fabrics selected for this research represented two weft knit structures, a single jersey and a double interlock structure. The following fibers were used in all structures: 100 percent cotton, 100 percent polyester, and 50/50 percent cotton/polyester. Descriptive fabric properties were measured in order to compare the selected test fabrics. The research was performed at 37°C. (98.6°F.), 30 percent relative humidity to replicate conditions in a hot, dry climate.

The second part of this research determined whether correlations existed between the following: (1) the individual tests in the moisture transport test series, (2) the four individual tests in the moisture transport test series and the various basic fabric properties frequently used as quick indicators of moisture transport, and (3) the various basic fabric properties used as indicators.

The data in this chapter are presented in the following sequence: (1) descriptive properties of the test fabrics, (2) moisture transport test series, and (3) correlation of (a) individual moisture transport tests in series, (b) individual moisture transport tests in series with basic fabric properties used as quick indicators, and (c) various basic fabric properties.

DESCRIPTIVE PROPERTIES OF TEST FABRICS

The two fabric variables controlled were fiber content and fabric structure. The knit fabrics selected were as similar as possible. However, it was not possible to control all fabric properties, since differences in fabric properties are created when the fiber content and/or fabric structure are varied. For example, differences in fabric thickness can result from a change in the fabric structure from a single to a double knit structure.

The knits selected represented commercially available knits currently used in ready-to-wear. The ranges for the descriptive properties of the test fabrics are given in Table 3. Descriptive properties for each test fabric are presented in Table 4. Additional data for descriptive fabric properties, including the U.S. customary units, are given in Appendixes C-E which include the complete yarn description, wales per unit area, and the percent of shrinkage. Complete data for thickness and weight, fabric properties also used in the correlation portion of this research, are given in the correlation section of this chapter.

Yarns from four of the knits selected had a tex of 17. Single jersey knits which contained cotton had a higher yarn number. Cotton knits generally use a higher yarn number to produce and maintain suitable fabric cover.

The range for the yarn twist appeared wide because polyester filament yarns contained no twist; whereas staple yarns contained twist. Textured polyester filament yarn used in knitting generally has no twist. The range for the yarn twist for cotton and cotton/polyester blend yarns was much smaller. The twist for cotton yarns was somewhat less than the twist in cotton/polyester yarns. The fiber length in staple yarns was very similar.

The highest percentage of shrinkage occurred in the cotton single jersey knit; the least shrinkage occurred in fabrics containing polyester. Interlock structures were more dimensionally stable than single jersey knits.

Table 3

Range of Fabric Properties for Comparison of Selected Knit Fabrics

Property Measured	Range of Fabric Properties	
	S.I. units	U.S. units
Yarn number	17-36 tex	150-322 denier
Yarn twist		
Filament	0 t.p.cm.-	0 t.p.i.-
Staple	3.8-5.7	9.6-14.4 t.p.i.
Fiber length	20-25 mm	.78-.98 in.
Wales per unit area (after scour)	11.0-15.8 w.p.cm.	26-37 w.p.in.
Shrinkage		
Warp	2-4%	2-4%
Weft	1-5%	1-5%
Thickness	.5-.8 mm	.02-.03 in
Weight	130-200 g/m^2	4-6 oz/yd^2

Table 4

Descriptive Properties of Selected Knit Fabrics*

Knit Structure	Fiber Content	Yarn No. (tex)	Yarn Twist (tpcm)	Fiber Length (mm)	Wales (cm)	% Shrinkage		Thickness (mm)	Weight (g/m^2)
						Warp	Weft		
Single	Cotton	36	3.8	25	11.0	4	5	.66	174
	Cotton/ Polyester	32	5.7	25	11.0	3	3	.63	191
	Polyester	17	0	f**	13.8	2	2	.53	146
Interlock	Cotton	17	4.3	20	15.4	3	3	.73	193
	Cotton/ Polyester	17	5.7	25	15.8	2	1	.81	200
	Polyester	17	0	f	14.6	2	2	.71	131

*S.I. units only; data in U.S. customary units in Appendixes C-E.

**f = filament

Polyester fabrics were more dimensionally stable than fabrics made from cotton fibers.

The single jersey knits were the thinnest and interlock knits were the thickest. Polyester jersey knit fabrics were the lightest in weight. Interlock knits were generally heavier in weight than jersey knits.

Although it was not possible to control all fabric variables, fabric properties other than the two controlled, fiber content and fabric structure, were measured and reported. It appears that the range of major fabric properties is acceptable for comparing moisture transport properties of these selected knit fabrics.

MOISTURE TRANSPORT TEST SERIES

No standard moisture transport test methods for textiles have been adopted by test associations in the United States. Canada has adopted a standard test method for vapor transport which uses the control dish method in ambient air.

A moisture transport test series which is capable of measuring both vapor and liquid transport was developed. The same basic test apparatus, based on a volumetric method, was used to test both moisture forms. A change in specimen mounting procedure was used to change from vapor to liquid moisture form.

The test series replicated several conditions which can exist during use. This was done by using the following four moisture transport tests: (1) vapor form/ambient air,

(2) vapor form/moderate air currents, (3) liquid form/ambient air, and (4) liquid form/moderate air currents. Tests were performed at 37°C. (98.6°F.) and 30 percent relative humidity to replicate environmental conditions in a hot, dry environment.

The test apparatus was a water-filled vessel attached to a capillary tube which was held even with the water level of the vessel. The specimen was mounted in a holder and placed over the water in the vessel. The amount of water lost from the capillary tube during the three-hour test period was measured in millimeters. This reading was converted to the rate of loss which was expressed in grams of water per square meter of fabric per 24 hours ($g/m^2/24$ hours).

The research design allowed four independent variables to be examined. Two were fabric variables, fiber content and fabric structure, and two were treatment variables, air velocity and moisture form. The statistical computer analysis used was a four-way analysis of variance.

This section presents the data from the moisture transport test series, and it analyzes each research hypothesis. Significance at probability levels of .05 and .01 is reported. Conclusions regarding each hypothesis will be stated briefly. Additional comments which attempt to explain the results will be presented in Chapter 5.

The research hypotheses are related to the major independent variables; these are also called the main effects. Statistical analysis of the interaction effects of the independent variables is also presented in this chapter.

Main Effects

The computer four-way analysis of variance found the following independent variables to be statistically significant at the .01 level: fabric structure, fiber content, and air velocity. Moisture form was not found to be statistically significant. Analysis of each main effect will be presented individually.

The raw data for the moisture transport test series are presented in Table 5. The raw data are the amount of water loss, in millimeters, from the capillary tube through 0.286 square meters of fabric during the three-hour time period. Conversion of the raw data to the rate of loss in $g/m^2/24$ hours was done by the computer. The F values needed to show statistical significance at the .05 and .01 levels are given in Appendix F.

Fiber content. Analysis of variance suggests that a statistically significant difference exists in the ability of various fibers to transport moisture. Table 6 presents the summary for the analysis of variance for fiber content. The level of significance for fiber content is .01 which is highly significant.

The null hypothesis which was the same as the research hypothesis stated that no significant differences

Table 5

Moisture Transport for Test Series

Fabric Structure	Fiber Content	VAPOR TRANSPORT									
		Ambient Air Currents					Moderate Air Currents				
		H_2O Loss mm* Replicate No.			Rate		H_2O Loss mm Replicate No.			Rate	
		1	2	3	$g/m^2/3$ hrs $x 10^{-2}$ (Mean)	$g/m^2/24$ hrs $x 10^{-2}$ (Mean)	1	2	3	$g/m^2/3$ hrs $x 10^{-2}$ (Mean)	$g/m^2/24$ hrs $x 10^{-2}$ (Mean
Control		7	6	5	2.32	18.6	31	33	32	12.4	99.2
I	P	1	1	1	0.39	3.10	23	14	13	0.65	5.17
I	C	2	2	7	0.79	6.20	2	0	2	0.52	4.13
I	C/P	0	0	0	0	0	12	7	9	3.62	28.93
J	P	0	0	0	0	0	10	12	11	4.25	34.10
J	C	0	0	0	0	0	3	5	3	1.42	11.37
J	C/P	4.5	5	4.5	1.89	14.47	5	5	3	1.68	13.43

*Data expressed as mm drop in meniscus for the 0.286 m^2 area of test specimen for 3 hrs.

CODE: I=Interlock; J=Jersey; P=Polyester; C=Cotton; C/P=50/50% Cotton Polyester

Table 5 (continued)

Moisture Transport for Test Series

Fabric Structure	Fiber Content	LIQUID TRANSPORT									
		Ambient Air Currents					Moderate Air Currents				
		H_2O Loss mm Replicate No.			Rate		H_2O Loss mm Replicate No.			Rate	
		1	2	3	$g/m^2/3$ hrs $x\ 10^{-2}$ (Mean)	$g/m^2/24$ hrs $x\ 10^{-2}$ (Mean)	1	2	3	$g/m^2/3$ hrs $x\ 10^{-2}$ (Mean)	$g/m^2/24$ hrs $x\ 10^{-2}$ (Mean)
Control		7	6	5	2.32	18.6	12	11	11	4.39	35.12
I	P	2	1	2	0.65	5.17	3	3	3	1.16	9.30
I	C	0	1	1	0.26	2.07	10	3	5	0.23	1.86
I	C/P	2	2	2	0.78	6.2	19	17	17	0.69	5.48
J	P	0	3	0	0.39	3.10	3	3	3	1.16	9.3
J	C	0	0	1	0.13	1.03	4	3	4	1.42	11.37
J	C/P	1	1	1	0.39	3.10	5	5	9	2.45	19.63

CODE: I=Interlock; J=Jersey; P=Polyester; C=Cotton; C/P=50/50% Cotton Polyester

Table 6

ANOVA Summary Table for Fiber Content, Moisture Transport Test Series

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Fiber Content	2	.14610	.07305	27.78**

**.01 level of significance--highly significant

exist in the ability of various fibers, 100 percent cotton, 100 percent polyester, and 50/50 percent cotton/polyester, to transport moisture. Analysis of variance suggested the research hypothesis was false; therefore, the research hypothesis must be rejected, since a statistically significant difference does exist between various fibers to transport moisture. A summary of the analysis of variance marginal means for fiber content is presented in Table 7.

Table 7

ANOVA Marginal Means for Fiber Content, Moisture Transport Test Series

Fiber Content	Transport Rate ($g/m^2/24$ hrs x 10^{-2})
100% cotton	6.846
50/50% cotton/polyester	17.567
100% polyester	14.467

Whenever an independent variable has more than two levels, analysis of variance indicates only that a significant difference exists between at least two levels within the independent variable. A statistically significant difference for a variable containing over two levels does not imply that each level differs from all other levels. To determine where the differences actually occur, a post-hoc test must be performed. A Newman-Keuls post-hoc analysis was performed because a statistically significant difference was found for fiber content, a variable with three levels. The calculations for the Newman-Keuls post-hoc analysis are given in Appendix G. The summary of findings for the Newman-Keuls post-hoc analysis for fiber content is given in Table 8.

Table 8

Summary Newman-Keuls Post-Hoc Statistical Analysis for Fiber Content, Moisture Transport Test Series

Fiber Content	Transport Rate ($g/m^2/24$ hrs x 10^{-2})
100% cotton ≠ 100% polyester	6.846 ≠ 14.467
100% cotton ≠ 50/50% cotton/ polyester	6.846 ≠ 17.567
Therefore, 100% cotton ≠ 100% polyester or 50/50% cotton/ polyester	6.846 ≠ 14.467 or 17.567
100% polyester = 50/50% cotton polyester	14.467 = 17.567

The Newman-Keuls post-hoc analysis for fiber content suggested 100 percent cotton, the slowest transporter, does not equal the fastest transporter, 50/50 percent cotton/polyester. Nor did 100 percent cotton equal the intermediate transporter, 100 percent polyester. Therefore, 100 percent cotton equaled neither 50/50 percent cotton/polyester nor 100 percent polyester. However, 50/50 percent cotton/polyester, the fastest transporter, was shown to equal 100 percent polyester.

Hence a statistically significant difference existed only between 100 percent cotton and the other two fiber contents used 100 percent polyester and 50/50 percent cotton/polyester. A statistically significant difference did not exist between the 100 percent polyester and the 50/50 percent cotton/polyester.

It was necessary to reject the research hypotheses concerning fiber content since some differences did exist in the ability of various fibers to transport moisture. However, not all fibers suggested a statistically significant difference in their ability to transport moisture.

It appears that it is not necessary to have a hydrophilic fiber to obtain sufficient moisture transport since the polyester did not transport moisture significantly different from the 50/50 percent cotton/polyester. The cotton fiber which transported moisture significantly slower than either 100 percent polyester or 50/50 percent cotton/polyester indicates that the need for the hydrophilic fiber may not be as great as once thought. The discussion of these results will be presented in Chapter 5.

Fabric structure. Analysis of variance suggests that a statistically significant difference exists in the ability of the two weft knit structures, the jersey and the interlock, to transport moisture. Table 9 presents the fabric structure summary for analysis of variance for the moisture transport test series. The level of significance for fabric structure is .01 which is considered highly significant.

Table 9

Summary Table for ANOVA Fabric Structure, Moisture Transport Test Series

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Fabric Structure	1	.05992	.05992	22.78**

**.01 level of significance--highly significant

The null hypothesis states that no significant differences exist in the ability of selected knit structures to transport moisture. Analysis of variance suggested the null hypothesis was false. There is a difference in the ability of the two knit structures, jersey and interlock, to transport moisture. Table 10 shows the analysis of variance marginal means for fabric structure.

Table 10

ANOVA Marginal Means for Fabric Structure,
Moisture Transport Test Series

Fabric Structure	Transport Rate (g/m^2/24 hrs x 10^{-2})
Jersey	10.075
Interlock	15.844

Analysis of variance suggested that the interlock knit structure transports significantly more moisture than the single jersey knit structure, as shown in Table 10. Research hypothesis two stated that the jersey knit structure would allow more moisture transport than the interlock structure. The research hypothesis must be rejected since the analysis of variance shows the interlock structure to transport significantly more moisture than the single jersey structure. However, significant differences do exist in the ability of the two-knit structure to transport moisture.

Fiber content/fabric structure. The third research hypothesis concerned which fabric variable would be more important in moisture transport through the knit, the fiber content or the fabric structure. The third hypothesis was based upon the results of the first and the second research hypotheses. The first research hypothesis predicted no difference in moisture transport due to fiber content. The second hypothesis suggested that the jersey structure would allow more transport than the interlock structure.

The third research hypothesis suggested that the knit fabric structure would be the more important fabric variable in moisture transport through selected knit fabrics than would the fiber content. Examination of the third research hypothesis was by examination of the results of the analysis of the first two research hypotheses.

The null hypothesis was that neither the fiber content nor fabric structure would be more important than the other in moisture transport through knit fabrics. According to the analysis of variance, both the fiber content and the fabric structure were statistically significant fabric variables. Therefore, it was not possible to say that either fabric variable was more important than the other in determining rate moisture transport in knit fabrics. The null hypothesis was accepted as being true; therefore, research hypothesis three was rejected. Both fabric variables, fiber content and fabric structure, should be considered when engineering knit fabrics for thermal comfort as related to evaporative cooling and maintenance of body temperature.

However, the results of the Newman-Keuls post-hoc statistical analysis performed on fiber content should perhaps be considered. Some significant differences due to fiber content did occur. The 100 percent cotton, the slowest transporter, significantly differed from both the 100 percent polyester and the 50/50 percent cotton/polyester. The 100 percent polyester did not significantly differ from the 50/50 percent cotton/polyester.

Moisture form. Analysis of variance suggests that no statistically significant differences exist between the vapor and liquid moisture forms. Table 11 presents the analysis of variance summary table for moisture form.

Table 11

ANOVA Summary for Moisture Form, Moisture Transport Test Series

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Moisture form	1	.00706	.00706	2.68

The null hypothesis stated that no significant differences exist in moisture transport between vapor and liquid forms. Analysis of variance suggested the null hypothesis was true. Therefore, the research hypothesis must be rejected. Liquid form does not result in more moisture transport than the vapor form. A summary of marginal means for the treatment variable, moisture form, is presented in Table 12.

Air velocity. Analysis of variance suggests that a statistically significant difference exists between the two levels of air velocity, a treatment variable. Table 13 presents the analysis of variance summary for air velocity. The level of significance is .01, which is highly significant.

Table 12

ANOVA Marginal Means for Moisture Form,
Moisture Transport Test Series

Moisture Form	Transport Rate ($g/m^2/24$ hrs x 10^{-2})
Vapor	13.950
Liquid	11.969

Table 13

ANOVA Summary for Air Velocity,
Moisture Transport Test Series

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Air Velocity	1	.61698	.61698	234.59**
Error Term	48	.12637	.00263	

**.01 level of significance--highly significant

The null hypothesis stated that no significant differences would exist in the rate of moisture transport between ambient air and moderate air currents. Analysis of variance shows the null hypothesis to be false. The research hypothesis stated that an increase in the rate of moisture transport would result from the use of moderate air currents. The moderate air currents produced a statistically significant higher transport rate than the test performed in ambient air. The research hypothesis stating that the use of moderate air currents will increase the moisture transport rate is accepted. A summary of marginal means for analysis of variance for the treatment variable air velocity is presented in Table 14.

Table 14

ANOVA Marginal Means for Air Velocity, Moisture Transport Test Series

Air Velocity	Transport Rate ($g/m^2/24$ hrs x 10^{-2})
Ambient	3.703
Moderate	22.217

An increase in air velocity from the use of ambient air to use of a moderate air current greatly increases the moisture transport rate.

<u>Summary of main effects</u>. This research indicates that to obtain thermal clothing comfort in relation to evaporative cooling and maintenance of body temperature in a hot, dry climate, the fabric variables, fiber content and fabric structure, should be considered. In some cases, the

fabric structure may be the more important consideration. In addition, the air velocity is an important factor in aiding the removal of perspiration.

Table 15 shows the complete analysis of variance summary table for main effects. Analysis of variance shows that both fabric variables, fiber content and fabric structure, were significant at the .01 level, which is considered highly significant. The treatment variable air velocity is also significant at the .01 level. Air velocity was not statistically significant.

Table 16 presents the cell means for all variables, and Table 17 presents the marginal means for all variables.

Table 15

ANOVA Summary of Main Effects,
Moisture Transport Test Series

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
MAIN EFFECTS:				
Fabric Variables:				
Fabric Structure	1	.05992	.05992	22.78**
Fiber Content	2	.14610	.07305	27.78**
Treatment Variables:				
Moisture Form	1	.00706	.00706	2.68
Air Velocity	1	.61698	.61698	234.59**

**.01 level of significance--highly significant

Table 16

ANOVA Cell Means for All Variables, Moisture Transport Test Series

FABRIC VARIABLES		TREATMENT VARIABLES Rate--g/m^2/24 hrs x 10^{-2}			
		VAPOR		LIQUID	
Fabric Structure	Fiber Content	Ambient	Moderate	Ambient	Moderate
Jersey	C	0	11.37	1.03	11.37
	C/P	14.47	13.43	3.10	19.63
	P	0	34.10	3.10	9.3
Interlock	C	6.20	4.13	2.07	1.86
	C/P	0	28.93	6.2	5.48
	P	3.10	5.17	5.17	9.30

CODE:
C = 100% cotton
C/P = 50/50% cotton/polyester
P = 100% polyester

Table 17

ANOVA Marginal Means for All Variables, Moisture Transport Test Series

Independent Variables	Levels of Variables	Marginal Means ($g/m^2/24$ hrs x 10^{-2})
FABRIC STRUCTURE	Jersey	10.075
	Interlock	15.844
FIBER CONTENT	100% Cotton	6.846
	100% Polyester	14.467
	50/50% Cotton/ Polyester	17.567
MOISTURE FORM	Liquid	11.969
	Vapor	13.950
AIR VELOCITY	Ambient	3.703
	Moderate	22.217

Interaction Effects

Interaction effects examine all possible combinations of variables to determine whether the combinations of variables are statistically significant. Interaction effects determine what special or additional effects are due to the unique combination of variables.

First order interaction effects are concerned with all possible combinations of two independent variables. Second order interactions examined all possible combinations of three independent variables. The third order interaction examined the combination of the four independent variables.

Due to the total possible number of interactions for this experiment, no research hypotheses were formulated for interaction effects. The results of the first, second, and third order interaction effects are reported in this chapter. The discussion of these interaction effects will be presented in Chapter 5.

Analysis of variance suggested that the following first order interactions are statistically significant at the .01 level:

Fabric structure/air velocity
Fiber content/moisture form
Fiber content/air velocity.

The following first order combinations of variables were not found to be statistically significant: fabric structure/fiber content, fabric structure/moisture form, and moisture form/air velocity. Table 18 presents the analysis of variance summary table for first order interaction effects.

Table 18

ANOVA Summary for First Order Interaction Effects, Moisture Transport Test Series

Combination of Variables	Degrees of Freedom	Sum of Squares	Mean Square	F
Fabric structure/ Fiber content	2	.01925	.00962	3.66
Fabric structure/ Moisture form	1	.00973	.00073	3.70
Fabric structure/ Air velocity	1	.05639	.05639	21.44**
Fiber content/ Moisture form	2	.16900	.08450	32.13**
Fiber content/ Air velocity	2	.08075	.04038	15.36**
Moisture form/ Air velocity	1	.00386	.00386	1.47

**.01 level of significance--highly significant

Three second order interactions were shown to be statistically significant. Fiber content/fabric structure/moisture form was significant at the .05 level. Both fiber content/fabric structure/air velocity and fiber content/moisture form/air velocity were significant at the .01 level which is highly significant.

The only second order combination of variables not found to be statistically significant was fabric structure/ moisture form/ air velocity. Table 19 presents the analysis of variance summary for the second order interaction effects.

Table 19

ANOVA Summary of Second Order Interaction Effects, Moisture Transport Test Series

Combination of Variables	Degrees of Freedom	Sum of Squares	Mean Square	F
FS/FC/MF	2	.05838	.02919	11.10*
FS/FC/AV	2	.09549	.04774	18.15**
FS/MF/AV	1	.00033	.00033	0.13
FC/MF/AV	2	.25581	.12791	48.63**

*.05 level of significance--significant
**.01 level of significance--highly significant

CODE: FS = Fabric structure; FC = Fiber content; AV = Air velocity; MF = Moisture form.

The only possible third order interaction effect was fiber content/fabric structure/moisture form/air velocity, which was not found to be statistically significant. The analysis of variance summary for the third order interaction is given in Table 20.

Table 20

ANOVA Summary of Third Order Interaction Effects, Moisture Transport Test Series

Combination of Variables	Degree of Freedom	Sum of Squares	Mean Square	F
FC/FS/MF/AV	2	.02453	.01227	4.67

CODE: FC = Fiber content; FS = Fabric structure; MF = Moisture form; AV = Air velocity.

Summary of Moisture Transport Test Series

The first part of this research used a series of moisture transport tests to replicate use conditions. Two independent fabric variables, fiber content and fabric structure, and two treatment variables, air velocity and moisture form, were analyzed. Several main effects and interaction effects were found to be statistically significant. Table 21 shows the main effects and interaction effects found to be statistically significant.

The complete analysis of variance summary table for the moisture transport test series is shown in Table 22. The discussion of the research findings is presented in Chapter 5.

Table 21

Summary of Statistically Significant Main Effects and Interaction Effects for the Moisture Transport Test Series

---

Main Effects:

Fabric Structure**
Fiber Content**
Air Velocity**

First Order Interaction Effects:

Fabric Structure/Air Velocity**
Fiber Content/Moisture Form**
Fiber Content/Air Velocity**

Second Order Interaction Effects:

Fabric Structure/Fiber Content/Moisture Form*
Fabric Structure/Fiber Content/Air Velocity**
Fiber Content/Moisture Form/Air Velocity**

---

*.01 level of significance--significant
**.05 level of significance--highly significant

Table 22

Analysis of Variance Summary Table for Moisture Transport Test Series

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
MAIN EFFECTS:				
Fabric Variables				
Fabric Structure	1	.05992	.05992	22.78**
Fiber Content	2	.14610	.07305	27.78**
Treatment Variables				
Moisture Form	1	.00706	.00706	2.68
Air Velocity	1	.61698	.61698	234.59**
FIRST ORDER INTERACTION EFFECTS:				
Fabric Structure/ Fiber Content	2	.01925	.00962	3.66
Fabric Structure/ Moisture Form	1	.00973	.00973	3.70
Fabric Structure/ Air Velocity	1	.05639	.05639	21.44**
Fiber Content/ Moisture Form	2	.16900	.08450	32.13**
Fiber Content/ Air Velocity	2	.08075	.04038	15.36**
Moisture Form/ Air Velocity	1	.00386	.00386	1.47
SECOND ORDER INTERACTION EFFECTS:				
FS/FC/MF	2	.05838	.02919	11.10*
FS/FC/AV	2	.09549	.04774	18.15**
FS/MF/AV	1	.00033	.00033	.13
FC/MF/AV	2	.25581	.12791	48.63**
THIRD ORDER INTERACTION EFFECTS:				
FS/FC/AV	2	.02453	.01227	4.67
Within replicates (error term)	48	.12637	.00263	
TOTAL	71	1.72995		

**.01 level of significance--highly significant
*.05 level of significance--significant

CORRELATIONS

Several basic fabric properties or quick tests have been used as indicators of moisture transport properties of fabrics. Most of these tests are quick and easy to perform; therefore, various combinations of these tests are frequently used. No standard test method has been adopted for moisture transport tests which perhaps encourages the use of several quick tests.

Basic fabric property or quick tests used in this research include the following: vertical wicking, drop absorption, percent moisture absorption, percent moisture regain, percent moisture imbibition, air permeability, thickness, and weight.

The Spearman rho rank order correlation computer program determined the correlation coefficients for all tests performed in this research. The correlation results are reported in three sections: (1) correlations between the moisture transport tests in the test series, (2) correlations between moisture transport tests in the series and the basic fabric property tests, and (3) correlations between the various basic fabric property tests. Correlations were considered statistically significant at the .01, .02, or .05 level of significance. In addition, the .10 and .20 levels of significance were reported and considered to represent a trend. Correlation coefficient values needed for all levels of significance are given in Appendix H.

The data and results are presented in this chapter; the discussion of results is in Chapter 5.

CORRELATION BETWEEN MOISTURE TRANSPORT TESTS IN THE SERIES

The moisture transport test series was designed to more fully replicate use conditions than did the vapor transport tests performed in ambient air or the basic fabric property tests used as indicators of moisture transport. The moisture transport test series varied: (1) the moisture form to include vapor and liquid forms, and (2) the air velocity to include ambient air and moderate air currents. A series of four tests were used in the series.

Correlation coefficients were examined to determine whether any statistically significant correlations existed between tests in the moisture transport test series. Correlation of tests in the series could possibly reduce the number of tests needed to be performed, thereby simplifying the testing procedure. Tests in the series which used the same moisture form or air velocity were examined to determine whether any correlation existed between them. This included the determination of correlation between the following tests:

1. Vapor form/ambient air and vapor form/moderate air currents.
2. Liquid form/ambient air and liquid form/moderate air currents.
3. Vapor form/ambient air and liquid form/ambient

air.

4. Vapor form/moderate air currents and liquid form/ moderate air currents.

Correlations Between Vapor Form/ Ambient Air and Vapor Form/ Moderate Air Currents

The Spearman rho correlation between the vapor form/ ambient air and the vapor form/moderate air currents from the moisture transport test series is presented in Table 23. The correlation between vapor form and variations in air currents, ambient air and moderate air currents, was not found to be statistically significant.

Table 23

Spearman Rho Correlation Between Vapor Form/Ambient Air and Vapor Form/Moderate Air Currents from the Moisture Transport Test Series

Variable	Vapor Form/Moderate Air Currents
Vapor Form/Ambient Air	-0.2732

Since no correlation was found between the vapor form/ ambient air and the vapor form/moderate air currents tests from the moisture transport test series, it is suggested that both tests be performed to replicate use conditions.

Correlations Between Liquid Form/ Ambient Air and the Liquid Form/ Moderate Air Currents

The Spearman rho correlation between the liquid form/ ambient air and the liquid form/moderate air currents from the moisture transport test series was not found to be statistically significant. The correlation between liquid form/ambient air and liquid form/moderate air currents is presented in Table 24.

Table 24

Spearman Rho Correlation Between Liquid Form/Ambient Air and Liquid Form/Moderate Air Currents from the Moisture Transport Test Series

Variable	Liquid Form/Moderate Air Currents
Liquid Form/Ambient Air	0.1324

Since no correlation was found between liquid form/ambient air and the liquid form/moderate air currents tests from the moisture transport test series, both tests should be performed to replicate use conditions.

Correlations Between Vapor Form/ Ambient Air and Liquid Form/ Ambient Air

The Spearman rho correlation between the vapor form/ ambient air and the liquid form/ambient air tests from the moisture transport test series is presented in Table 25. No statistical significance was found between the two tests.

Both tests should be performed to replicate use conditions.

Table 25

Spearman Rho Correlation Between Vapor Form/Ambient Air and Liquid Form/Ambient Air from the Moisture Transport Test Series

Variable	Liquid Form/Ambient Air
Vapor Form/Ambient Air	-0.0924

Correlations Between Vapor Form/ Moderate Air Currents and Liquid Form/Moderate Air Currents Tests

The Spearman rho correlation between the vapor form/ moderate air currents and the liquid form/moderate air currents tests from the moisture transport test series were not found to be statistically significant. The correlation coefficient is shown in Table 26.

Table 26

Spearman Rho Correlation Between Vapor Form/Moderate Air Currents and Liquid Form/Moderate Air Currents from the Moisture Transport Test Series

Variable	Liquid Form/ Moderate Air Currents
Vapor Form/ Moderate Air Currents	-0.5798

Since no significant correlation was found between the vapor form/moderate air currents and the liquid form/moderate air currents, it is suggested that both tests be performed to replicate use conditions.

Summary of Correlations Between Tests in the Moisture Transport Test Series

No statistically significant correlations were found between tests using either the same moisture form or the same air currents. The summary of Spearman rho rank order correlations between moisture transport tests in the test series is presented in Table 27.

Table 27

Summary of Spearman Rho Rank Order Correlations Between Tests in the Moisture Transport Test Series

Variable	Vapor/ Ambient	Vapor/ Moderate	Liquid/ Ambient	Liquid/ Moderate
Vapor/ Ambient		-0.2732	-0.0924	0.1540
Vapor/ Moderate			0.7247^{+}	-0.5798
Liquid/ Ambient				0.1324

$^{+}$p .20 weak trend

Examination of Table 27 shows no statistically significant Spearman rho rank order correlations between tests in the moisture transport test series. The correlation coefficient between vapor form/moderate air currents was 0.7247 which suggests a trend. These two tests used a different moisture form and air velocity. Since no statistically significant Spearman rho rank order correlations were found between moisture transport tests using either the same moisture form or air velocity, use of all four tests in the moisture transport test series is recommended to more fully replicate use conditions.

Correlation Between Tests in Moisture Transport Series and Fabric Property Tests Used as Indicators

This section examines whether any statistically significant correlations exist between tests in the moisture transport test series and tests for basic fabric properties often used as indicators of moisture transport. This is related to whether basic fabric tests really are indicators of moisture transport properties of textiles for various use conditions. If basic fabric property tests are found which correlate with the series of moisture transport tests, perhaps testing could be simplified and the testing time reduced. This would perhaps encourage more fabric producers and apparel manufacturers to test moisture transport properties of fabrics. The data and results are presented in this chapter; Chapter 5 contains the discussion of the results.

Correlation Between Tests in the Moisture Transport Test Series and Vertical Wicking

Spearman rho correlations between moisture transport tests in the test series and the vertical wicking tests, five minutes in the warp and filling directions, were not statistically significant at the .05 level. However, a negative correlation coefficient of -0.7537 was shown between the liquid form/ambient air test in the series and the vertical wicking test, warp and filling directions. This suggests a trend at the .20 level of probability. The correlation between the tests in the moisture transport test series and the vertical wicking tests are shown in Table 28.

Table 28

Correlation Between Tests in the Moisture Transport Test Series and Vertical Wicking Tests

Variable	Vertical Wicking Test*	
	Warp	Filling
Moisture Transport Test:		
Vapor/Ambient	0.1518	0.1518
Vapor/Moderate	0.4857	0.4857
Liquid/Ambient	-0.7537+	-0.7537+
Liquid/Moderate	-0.2319	-0.2319

+.20 level of significance--weak trend
*5 min. time period

Vertical wicking tests, warp or weft direction, did not show statistically significant correlations with tests in the moisture transport test series. The vertical wicking test would not serve as an indicator of moisture transport properties of fabrics.

Results of the vertical wicking tests, five minutes warp and filling directions, are given in Table 29. Results of the moisture transport tests were presented in Table 5.

Table 29

Vertical Wicking Tests

	Fiber Content	Fabric Structure	Warp (5 min)		Filling (5 min)	
			S.I. (cm)	U.S. (in)	S.I. (cm)	U.S. (in)
100%	Cotton	Jersey	41	16	39	16
100%	Cotton	Interlock	41	16	43	17
50/50%	Cotton/ Polyester	Jersey	16	6	12	5
50/50%	Cotton/ Polyester	Interlock	5	2	9	4
100%	Polyester	Jersey	18	7	23	9
100%	Polyester	Interlock	28	11	32	13

Correlation Between Tests in the Moisture Transport Test Series and Drop Absorption

Spearman rho correlation between moisture transport tests in the series and drop absorption, complete penetration for both the face and back, was not found to be statistically significant at the .05 level. However, a correlation of 0.6957 between vapor form/moderate air currents moisture transport test and drop absorption suggests a trend with a .20 level of probability. The correlations between the moisture transport tests in the series and drop absorption, face and back, are shown in Table 30.

Table 30

Correlation Between Tests in the Moisture Transport Test Series and Drop Absorption

Variable	Drop Absorption--Complete Penetration Face	Drop Absorption--Complete Penetration Back
Moisture Transport Tests:		
Vapor/Ambient	0.0616	0.0616
Vapor/Moderate	0.6957^{+}	0.6957^{+}
Liquid/Ambient	0.4412	0.4412
Liquid/Moderate	-0.5000	0.5000

$^{+}$p .20--weak trend

Drop absorption tests, complete penetration for face and back, did not show any statistically significant correlations with tests in the moisture transport test series. On this basis, drop absorption tests would not serve as an accurate indicator of moisture transport properties of fabrics. Results of the drop absorption tests are given in Table 31.

Table 31

Drop Absorption Tests

	Fiber Content	Fabric Structure	Drop Absorption--Complete Penetration	
			Face (sec)	Back (sec)
100%	Cotton	Jersey	1	1
100%	Cotton	Interlock	1	1
50/50%	Cotton/ Polyester	Jersey	337	438
50/50%	Cotton/ Polyester	Interlock	138	138
100%	Polyester	Jersey	900	628
100%	Polyester	Interlock	300	357

Correlation Between Tests in the Moisture Transport Test Series and Percent of Moisture Regain

A highly significant statistical correlation, .02 level of significance, was shown to exist between the liquid form/moderate air currents test in the series and the percent of moisture regain. No other statistically significant correlations were found between other tests in the moisture transport test series and the percent of moisture regain. Results of the Spearman rho rank order correlation are shown in Table 32.

Table 32

Correlation Between Tests in the Moisture Transport Test Series and the Percent of Moisture Absorption

Variable	Percent Moisture Regain
Moisture Transport Tests:	
Vapor/Ambient	0.0911
Vapor/Moderate	-0.6000
Liquid/Ambient	0.0870
Liquid/Moderate	0.9856**

**.02 level of significance--highly significant

The percent of moisture regain did show a statistically significant correlation with the liquid for moderate air currents tests. A summary of basic fabric properties which showed a significant correlation with tests in the moisture transport series will be presented at the end of this chapter to determine if all tests in the series were found to correlate with at least one basic fabric property test. Results of the percent of moisture regain test are presented in Table 33.

Correlation Between Tests in the Moisture Transport Test Series and the Percent Saturation Moisture Regain

Spearman rho rank order correlation between moisture transport tests in the series and the percent saturation moisture regain were not found to be statistically significant at the .05 level. The Spearman rho correlation coefficients between moisture transport tests in the series and the percent saturation moisture regain are presented in Table 34.

Table 33

Percent Moisture Regain Tests

	Fiber Content	Fabric Structure	Percent Moisture Regain
100%	Cotton	Jersey	6.51
100%	Cotton	Interlock	7.76
50/50%	Cotton/ Polyester	Jersey	7.36
50/50%	Cotton/ Polyester	Interlock	8.30
100%	Polyester	Jersey	2.50
100%	Polyester	Interlock	1.36

Table 34

Correlation Between Tests in the Moisture Transport Test Series and the Percent Saturation Moisture Regain

Variable	Percent Saturation Moisture Regain
Vapor/Ambient	0.2732
Vapor/Moderate	-0.2571
Liquid/Ambient	0.0580
Liquid/Moderate	0.3769

The percent saturation moisture regain did not show any statistically significant correlations with tests in the moisture transport test series. Therefore, percent saturation moisture regain would not serve as an indicator of moisture transport properties of fabrics as related to use conditions replicated by the moisture transport test series. Results of the percent saturation moisture regain tests are given in Table 35. Discussion of the findings will be presented in Chapter 5.

Table 35

Percent Saturation Moisture Regain Tests

	Fiber Content	Fabric Structure	Percent Saturation Moisture Regain
100%	Cotton	Jersey	231.54
100%	Cotton	Interlock	289.23
50/50%	Cotton/ Polyester	Jersey	172.95
50/50%	Cotton/ Polyester	Interlock	277.07
100%	Polyester	Jersey	164.70
100%	Polyester	Interlock	283.20

Correlation Between Tests in the Moisture Transport Test Series and the Percent Moisture Imbibition

A highly significant statistical correlation, .02 level of significance, was found between the vapor form/

moderate air currents moisture transport test in the series and the percent of moisture imbibition. An inverse relationship between these two tests was shown to exist. No other correlations between tests in the moisture transport test series and the percent of moisture imbibition were found to be significant. The Spearman rho correlation coefficients between tests in the moisture transport test series and the percent of moisture imbibition are presented in Table 36.

Table 36

Correlation Between Tests in the Moisture Transport Test Series and the Percent Moisture Imbibition

Variable	Percent Moisture Imbibition
Moisture Transport Tests:	
Vapor/Ambient	0.3947
Vapor/Moderate	-0.9429**
Liquid/Ambient	-0.6377
Liquid/Moderate	0.5798

**.02 level of significance--highly significant

Results of the percent moisture imbibition tests are given in Table 37.

Table 37

Percent Moisture Imbibition Tests

	Fiber Content	Fabric Structure	Percent Moisture Imbibition
100%	Cotton	Jersey	64.84
100%	Cotton	Interlock	76.23
50/50%	Cotton/ Polyester	Jersey	54.16
50/50%	Cotton/ Polyester	Interlock	50.94
100%	Polyester	Jersey	21.78
100%	Polyester	Interlock	24.14

<u>Correlation Between Tests in the Moisture Transport Test Series and Air Permeability</u>

Spearman rho rank order correlation between tests in the moisture transport test series and air permeability were not statistically significant at the .05 level of significance. However, a correlation at the .10 level of significance which indicates a trend was found between air permeability and two tests from the moisture transport test series, vapor form/moderate air currents and liquid form/moderate air currents. The moderate air currents were contained in both moisture transport tests which showed a trend toward correlation with air permeability. Results of the correlation between air permeability and tests in the moisture transport test series are shown in Table 38.

Table 38

Correlation Between Tests in the Moisture Transport Test Series and Air Permeability

Variable	Air Permeability
Moisture Transport Tests:	
Vapor/Ambient	-0.0304
Vapor/Moderate	0.8286++
Liquid/Ambient	0.2899
Liquid/Moderate	-0.8697++

++.10 level of significance--trend

Air permeability did not show any statistically significant correlations with tests in the moisture transport test series. Use of air permeability as an indicator of moisture transport properties of fabrics is therefore not recommended. However, a trend with a .10 level of significance was shown to exist between air permeability and the two tests using the moderate air currents. Table 39 presents data from the air permeability tests.

Correlation Between Tests in the Moisture Transport Test Series and Fabric Thickness

Spearman rho correlation between the tests in the moisture transport series and thickness were not statistically significant at the .05 level. However, correlation between the liquid form/moderate air currents and thickness was at the .20 level, which indicates a weak trend. The correlation between the tests in the moisture transport test series and fabric thickness are presented in Table 40.

Table 39

Air Permeability Tests

	Fiber Content	Fabric Structure	Air Permeability S.I. ($cm^3/cm^2/sec$)	Air Permeability U.S.** ($ft^3/ft^2/min$)
100%	Cotton	Jersey	122.9	242.0
100%	Cotton	Interlock	75.4	148.5
50/50%	Cotton/ Polyester	Jersey	152.4	300.0
50/50%	Cotton/ Polyester	Interlock	97.5	192.0
100%	Polyester	Jersey	305.8	602.0
100%	Polyester	Interlock	311.0	613.0

**Original reading obtained in U.S. units.

Table 40

Correlation Between Tests in Moisture Transport Test Series and Fabric Thickness

Variable	Fabric Thickness
Moisture Transport Tests:	
Vapor/Ambient	-0.0304
Vapor/Moderate	-0.2000
Liquid/Ambient	0.3479
Liquid/Moderate	0.6957+

+.20 level of significance--weak trend

Fabric thickness did not show any statistically significant correlations with tests in the moisture transport test series. A trend was indicated between liquid form/moderate air currents and fabric thickness. However, use of fabric thickness to indicate moisture transport properties of fabrics is not recommended. Results of the fabric thickness tests are shown in Table 41.

Table 41

Fabric Thickness Tests

	Fiber Content	Fabric Structure	Fabric Thickness S.I. (mm)	Fabric Thickness U.S. (in)
100%	Cotton	Jersey	.66	.026
100%	Cotton	Interlock	.73	.029
50/50%	Cotton/ Polyester	Jersey	.63	.025
50/50%	Cotton/ Polyester	Interlock	.81	.032
100%	Polyester	Jersey	.53	.021
100%	Polyester	Interlock	.71	.028

Correlation Between Tests in the Moisture Transport Test Series and Fabric Weight

A statistically significant correlation, at the .02 level of significance, was found between liquid form/moderate air currents test and fabric weight. No other statistically significant correlations between other tests in the moisture transport test series and the fabric weight were found. The Spearman rho rank order correlations between the tests in the moisture transport test series and fabric weight are shown in Table 42.

Table 42

Spearman Rho Correlation Between Tests in the Moisture Transport Test Series and Fabric Weight

Variable	Fabric Weight
Moisture Transport Tests:	
Vapor/Ambient	0.0911
Vapor/Moderate	-0.6000
Liquid/Ambient	0.0870
Liquid/Moderate	0.9856**

**.02 level of significance--highly significant

Results of fabric weight are presented in Table 43.

<u>Summary of Correlations Between Tests in the Moisture Transport Test Series and Basic Fabric Property Tests, by Moisture Transport Tests</u>

The summary of correlations between tests in the moisture transport test series and basic fabric property tests is shown in Table 44.

No basic fabric property tests were found which showed a statistically significant correlation with the vapor form/ambient air test in the moisture transport test series.

Table 43

Fabric Weight

	Fiber Content	Fabric Structure	Fabric Weight* S.I. (g/m^2)	Fabric Weight* U.S. (oz/yd^2)
100%	Cotton	Jersey	174	5
100%	Cotton	Interlock	193	6
50/50%	Cotton/ Polyester	Jersey	191	6
50/50%	Cotton/ Polyester	Interlock	200	6
100%	Polyester	Jersey	146	4
100%	Polyester	Interlock	131	4

Drop absorption, complete penetration face and back, showed a correlation with vapor form/moderate air current test from the moisture transport test series at the .20 level of significance which indicates a weak trend. A correlation of .10, which indicates a trend, was shown between vapor form/moderate air current test from the moisture transport test series and air permeability. A correlation of .02 level of significance existed between the vapor form/moderate air currents and the percent moisture imbibition.

The only fabric property to show a weak correlation at the .10 level of significance with the liquid form/

Table 44

Correlation Coefficients Between Tests in the Moisture Transport Test Series and Basic Fabric Property Tests

Basic Fabric Properties	Vapor/ Ambient	Vapor/ Moderate	Liquid/ Ambient	Liquid/ Moderate
Wicking, Filling	0.01518	-0.4857	-0.7537^{+}	-0.2319
Wicking, Warp	0.1518	-0.4857	-0.7537^{+}	-0.2319
Drop Absorption, Face	0.0616	0.6957^{+}	0.4412	-0.5000
Drop Absorption, Back	0.0616	0.6957^{+}	0.4412	-0.5000
% Moisture Regain	0.0911	-0.6000	0.0870	0.9856**
% Saturation Regain	0.2732	-0.2571	0.0580	0.3769
% Imbibition	0.3947	-0.9429**	-0.6377	0.5798
Air Permeability	-0.0304	0.8286^{++}	0.2899	-0.8697^{++}
Thickness	-0.0304	-0.2000	0.3479	0.6957^{+}
Weight	0.0911	-0.6000	0.0870	0.9856**

***.01 level of significance--perfect
**.02 level of significance--highly significant
*.05 level of significance--significant
$^{++}$.10 level of significance--trend
$^{+}$.20 level of significance--weak trend

ambient air test was the vertical wicking test, warp and weft directions.

Liquid form/moderate air current test from the moisture transport test series showed a correlation at the .02 level of significance with the percent moisture regain and with fabric weight. A trend was shown to exist between liquid form/moderate air currents and air permeability and fabric thickness.

The liquid form/moderate air currents test in the series correlated at the .02 level of significance with two basic fabric property tests and two trends were shown with basic fabric property tests. The vapor form/moderate currents showed a statistically significant correlation at the .02 level of significance with a basic fabric property and three trends were indicated. Both tests were performed using a moderate air current, but the moisture form differed.

Table 45 shows a summary of basic fabric properties which showed a trend or a statistically significant correlation with tests in the moisture transport series.

No fabric property test was found to have a statistically significant correlation at the .05 level with more than one test in the moisture transport test series. It appears that the basic fabric property tests used as quick indicators only represent one aspect of the use situation. No one indicator nor set of indicators were found which could give results similar to the tests in the moisture transport test series. Therefore, use of the moisture transport test series to replicate use conditions is recommended over the use of various basic fabric property tests.

Table 45

Summary of Spearman Rho Correlations Which Were Statistically Significant or Indicated a Trend

Moisture Transport Test	Basic Fabric Property Test
Vapor/Ambient	None
Vapor/Moderate	% Moisture Imbibition** Air Permeability++ Drop Absorption++
Liquid/Ambient	Vertical wicking, warp and weft++
Liquid/Moderate	% Moisture Regain** Fabric Weight** Air Permeability++ Fabric Thickness+

**.02 level of significance--highly significant
++.10 level of significance--trend
+.20 level of significance--weak trend

Summary of Correlations by Fabric Property

The vertical wicking test showed a weak trend, .20 level of significance, with the liquid form/moderate air current test. Drop penetration showed a weak trend, .20 level of significance, with the vapor form/moderate air current test.

The percent moisture regain showed a significant correlation, at the .02 level, with the liquid form/moderate air current test. The percent saturation moisture regain showed no correlations with any of the tests in the moisture transport test series. The percent of moisture imbibition showed a correlation statistically significant at the .02 level of significance with the vapor form/moderate air current test.

Air permeability was statistically significant at the .02 level of significance, with both the vapor form/moderate air currents and the liquid form/moderate air currents. Both moisture transport tests that were shown to correlate with air permeability were performed using moderate air currents.

The thickness showed a weak trend at the .20 level of significance with liquid form/moderate air currents. Fabric weight also suggested a trend, .20 level of significance, with liquid form/moderate air currents.

The only basic fabric property which even indicated a trend toward correlation with more than one of the tests in the moisture transport test series was air permeability. Air permeability at the .10 level of significance suggested a trend with vapor form/moderate air currents and liquid form/moderate air currents.

CORRELATIONS BETWEEN BASIC FABRIC PROPERTY TESTS

The Spearman rho correlation computer analysis included the correlation coefficients between the various basic fabric property tests. It was considered desirable to examine the Spearman rho correlation coefficients between the various basic fabric properties to determine whether any basic fabric property test was related to others.

Correlation Between Vertical Wicking, Warp and Filling and Other Fabric Properties

Vertical wicking showed a perfect correlation between the filling and the warp direction. This would not be automatically expected, since a knit fabric differs greatly in the warp and filling directions. Vertical wicking did not correlate with any of the other basic fabric properties. The Spearman rho correlation coefficients between vertical wicking and the other various fabric property tests are presented in Table 46.

Correlation Between Drop Absorption and Other Fabric Properties

Drop absorption showed a perfect correlation between the face and back side of the fabric. This again might seem to be an expected result, but the face and back side of the single knits vary greatly. Generally this test is performed with the water dropping onto the face of the fabric. During wear, perspiration first comes into contact with the back side of the fabric.

Other trends were shown between drop absorption and the following fabric properties: the percent saturation moisture regain, the percent moisture imbibition, air permeability, and the fabric thickness. Table 47 shows the Spearman rho correlation between drop absorption and other fabric properties.

Table 46

Spearman Rho Correlation Between Vertical Wicking and Other Fabric Properties

Variable	Vertical Wicking	
	Filling	Warp
Wicking, filling		1.0000***
Wicking, warp	1.0000***	
Drop Absorption, face	-0.5798	-0.5798
Drop Absorption, back	-0.5798	-0.5798
% Moisture Regain	-0.2571	-0.2571
% Saturation Regain	0.4857	0.4857
% Moisture Imbibition	0.5429	0.5429
Air Permeability	-0.2000	-0.2000
Thickness	0.0286	0.0286
Weight	-0.2571	0.2571

***.01 level of significance--perfect correlation

Table 47

Spearman Rho Correlation Between Drop Absorption and Other Fabric Property Tests

Variable	Drop Absorption	
	Face	Back
Drop Absorption, face		1.0000***
Drop Absorption, back	1.0000***	
% Moisture Regain	-0.4348	-0.4348
% Saturation Regain	-0.6957^{++}	-0.5957^{++}
% Moisture Imbibition	-0.8117^{++}	-0.8117^{++}
Air Permeability	0.7247^{++}	0.7247^{++}
Thickness	-0.6667^{++}	-0.6667^{++}
Weight	-0.4348	-0.4348

***.01 level of significance--perfect correlation
$^{++}$.10 level of significance--trend

Correlation Between the Percent Moisture Regain and Other Fabric Properties

The percent moisture regain did not show any correlation between the percent saturation regain or the percent of moisture imbibition. A perfect correlation was, however, shown with fabric weight. A correlation significant at the .05 level was also shown to exist between the percent of moisture regain and air permeability. Table 48 shows the correlations between the percent moisture regain and other fabric properties.

Table 48

Correlation Between the Percent Moisture Regain and Other Fabric Properties

Variable	% Moisture Regain
% Saturation Regain	0.2571
% Moisture Imbibition	0.5429
Air Permeability	-0.8857*
Thickness	0.6000
Weight	1.000***
Wicking, Warp and Filling	-0.2571
Drop Absorption, Face and Back	-0.4348

***.01 level of significance--perfect correlation
*.05 level of significance--significant

Correlation Between the Percent Saturation Moisture Regain and Other Fabric Properties

The percent moisture regain showed a correlation trend with thickness at the .10 level and drop absorption at the .20 level. Table 49 presents correlation coefficients between the percent saturation regain and other fabric properties.

Correlation Between Percent Moisture Imbibition and Other Fabric Properties

The percent moisture imbibition showed a weak trend with air permeability and drop absorption, face and back, which was significant at the .20 level of confidence.

Table 50 presents the correlations between the percent moisture imbibition and other fabric properties.

Table 49

Correlation Between Percent Moisture Saturation Regain and Other Fabric Properties

Variable	% Saturation Regain
% Moisture Imbibition	0.4857
Air Permeability	-0.4286
Thickness	0.8286++
Weight	0.2571
Wicking, Warp and Filling	0.4857
Drop Absorption, Face and Back	-0.6957+
% Moisture Regain	0.2571

++.10 level of significance--trend

+.20 level of significance--weak trend

Table 50

Correlation Between Percent Moisture Imbibition and Other Fabric Properties

Variable	% Moisture Imbibition
Air Permeability	-0.7714+
Thickness	0.3714
Weight	0.5429
Wicking, Warp and Filling	0.5429
Drop Absorption, Face and Back	-0.8117+
% Moisture Regain	0.5429
% Saturation Regain	0.4857

+.20 level of significance--weak trend

Correlation of Air Permeability and Other Fabric Properties

A statistically significant Spearman rho correlation was found between air permeability and the percent moisture regain, .05 level of significance. Trends also existed between air permeability and drop absorption, face and back, and the percent moisture imbibition at the .20 level of significance. Table 51 shows the Spearman rho correlation between air permeability and other fabric property tests.

Table 51

Spearman Rho Correlation Between Air Permeability and Other Fabric Property Tests

Variable	Air Permeability
Thickness	-0.6000
Weight	-0.8857
Wicking, Warp and Filling	-0.2000
Drop Absorption, Face and Back	0.7247+
% Moisture Regain	-0.8857*
% Saturation Regain	-0.4286
% Imbibition	-0.7714+
% Moisture	-0.7714+

*.05 level of significance--significant

+.20 level of significance--weak trend

Correlation Between Thickness and Other Fabric Properties

Trends were indicated between thickness and two other fabric properties. A weak trend, .20 level, existed between thickness and drop absorption. A trend, .10 level, existed between thickness and the percent saturation moisture regain. Table 52 presents the correlations between thickness and other fabric property tests.

Table 52

Spearman Rho Correlation Between Thickness and Other Fabric Properties

Variable	Thickness
Weight	0.6000
Wicking, Warp and Filling	0.0286
Drop Absorption, Face and Back	-0.6667+
% Moisture Regain	0.6000
% Saturation Regain	0.8286++
% Moisture Imbibition	0.3714
Air Permeability	-0.6000

++.20 level of significance--trend

+.10 level of significance--weak trend

Correlation Between Weight and Other Fabric Properties

A very highly significant correlation at the .01 level was shown to exist between weight and the percent moisture regain. Another correlation, significant at the .05 level, was shown to exist between weight and air permeability. Table 53 presents the correlations between weight and other fabric property tests.

Table 53

Correlations Between Weight and Other Fabric Properties

Variable	Weight
Wicking, Warp and Filling	-0.2571
Drop Absorption, Face and Back	-0.4348
% Moisture Regain	1.0000***
% Saturation Regain	0.2571
% Moisture Imbibition	0.5429
Air Permeability	-0.8857*
Thickness	0.6000

***.01 level of significance--perfect correlation
*.05 level of significance--significant

Chapter 5

DISCUSSION OF RESULTS

This research studied moisture transport properties of six commercially available weft knit fabrics. The study examined two fabric variables, fiber content and fabric structure, to determine their role in moisture transport. One hundred percent polyester, 100 percent cotton, and a 50/50 percent cotton/polyester blend were chosen to represent a hydrophilic fiber, a hydrophobic fiber, and a blend of both. The two weft knit structures available in all fiber contents were a single jersey and interlock knit.

No standard moisture transport test method has been adopted. The researcher developed a series of four moisture transport tests to replicate use conditions, which included variations in moisture form and air velocity. The first part of the research examined two major fabric variables, fiber content and fabric structure, and two treatment variables, air velocity and moisture form. The moisture transport test series was used. Computer four-way analysis of variance was used to statistically analyze the data.

In addition, other basic fabric property tests, which are frequently used to indicate moisture transport properties of fabrics, were performed. The second part of this research used Spearman rho rank order correlation to determine whether any correlations existed between the following tests: (1) individual tests in the moisture transport test series, (2) individual tests in the moisture transport series and basic fabric property tests, and (3) any of the basic fabric property tests with one another.

This chapter will discuss the results of the following tests: moisture transport series, correlation of various tests, and additional discussion of basic fabric property tests. It will also present suggestions for additional research.

MOISTURE TRANSPORT TEST SERIES

Fiber Content

Most early moisture transport research placed more emphasis on the role of fiber content than on the role of fabric structure. Until recently, researchers believed that it was necessary to have a hydrophilic fiber such as cotton to provide sufficient moisture transport. Recently, research has begun to suggest that the fiber content is less important than previously believed. The need for using a hydrophilic fiber is being questioned, but the controversy concerning hydrophilic versus hydrophobic fibers has not been completely resolved.

Little research has studied the effect that blending fibers has on moisture transport. Knight, in a recent study using natural, synthetic, and blended knits, suggested that no statistically significant differences existed in water vapor transport due to differences in fiber content.

Research hypothesis one for this research stated that no significant differences in moisture transport would result from differences in the fiber content. Analysis of variance suggested that the 50/50 percent cotton/polyester and the 100 percent polyester transported moisture at a significantly faster rate than the 100 percent cotton.

Although the results concerning fiber content were not predicted, the results suggest that hydrophilic polyester and a blend of 50/50 percent cotton/polyester transport moisture at a faster rate than 100 percent cotton. The findings suggest that it is not necessary for the fabric to be made entirely from hydrophilic fibers to promote moisture transport. It appears that polyester and polyester/cotton blends in weft knits can transport moisture. Perhaps some of the opinions which state that polyester is a slow moisture transporter developed from wearing polyester which was tightly woven.

Behmann (26) suggested that more severe test conditions were responsible for differences in moisture transport properties related to fiber content. Perhaps environmental and test conditions used were a factor. Most previous research studied woven fabrics, measured only vapor transport in ambient air, and used standard textile testing environmental conditions.

Hoffman and Peterson (79) have suggested earlier that blending might improve moisture transport properties of knit fabrics. Knight, in another study examining knit fabrics with various levels of hydrophobic and hydrophilic fibers, did not suggest such a possibility.

Moisture transport mechanisms must be considered in an explanation of results. The moisture transport test series measured only the total quantity of moisture transported. No tests capable of quantitatively measuring each transport mechanism in addition to determining the total amount of moisture transport have been developed.

Until recently, the most important moisture transport mechanism was considered to be fiber absorption-desorption into the environment. More recently, as researchers started suggesting that synthetic fibers were capable of providing sufficient moisture transport, they suggested the importance of capillary transport and migration along the fiber's surface.

In this research, both the 100 percent polyester and the 50/50 percent cotton/polyester weft knits transported moisture, vapor and liquid forms, significantly faster than the 100 percent cotton weft knits. Polyester does not absorb moisture into the fiber; therefore, moisture transport must be achieved by another mechanism. This implies that migration along the fiber's surface and capillary transport are important transport mechanisms.

Knit fabrics containing cotton have received a cross-linking resin finish which reduces the absorbency of cotton. This finish would probably reduce the effectiveness of the absorption-desorption mechanism. Still, finished cotton fibers are more absorbent than all polyester fibers. Also, moisture held and transported in structure, not just in fiber. Resin finish also changes surface wettability of cotton.

The 50/50 percent cotton/polyester weft knit fabrics were the fastest moisture transporters. Perhaps the blend functions to increase the number of moisture transport mechanisms. The cotton fibers would transport via the absorption-desorption mechanism. The polyester fibers would transport by migration along the fiber's surface and capillary transport.

The literature also suggests that the swelling of cotton can possibly reduce transport by preventing transport by the diffusion mechanism. Perhaps the addition of polyester to cotton could reduce this blocking effect.

Fabric Structure

The second research hypothesis stated that the more open weft jersey knit structure would allow more moisture transport than the interlock knit structure. Four-way analysis of variance suggested that the weft jersey knit structures transported significantly more moisture, vapor and liquid forms with and without moderate air currents, than the weft interlock structures.

The prediction was based on the results of previous research, mainly on woven fabrics. The prediction of more moisture transport for the more open knits related to the diffusion as a moisture transport mechanism. Previous research suggested that a more open structure would allow more moisture transport and would, therefore, be more comfortable in hot climates. It was also expected that the more open structures would be more greatly aided by the moderate air currents.

Most previous research which examined the role of fabric structure in moisture transport studied only woven fabric structures. Knight's research (7) suggested that weft knit structures transported significantly more moisture than the weft rib knit structure. No explanation for the differences in results was suggested. However, this research did serve as a basis for expecting differences in the ability of various knit structures to transport moisture.

Popular opinion suggests that tightly woven fabrics are uncomfortable because they do not allow sufficient moisture to escape. The moisture builds up between the skin and fabric, thus creating a "clammy feeling." Tightly woven synthetic fabrics especially have this reputation, since they provide no moisture transport through the fiber itself.

The results related to the fabric structure in this study may reflect structural differences between woven and knit fabrics. The prediction was mainly based on research performed on woven fabrics. The range of openness for knit fabrics used in apparel is not so wide as the range of openness for woven fabrics used in apparel. Knit fabrics generally contain more air space, and knits range from moderately open structures to open structures. Perhaps both of the knit structures studied in this research, the interlock and the weft jersey, were both open enough to prevent the severe decrease in moisture transport. Neither knit structure was tight enough to severely inhibit transport.

The results might not be related so much to the openness of the fabric structure as predicted but to the arrangement of the air spaces. Both knit structures have the same basic loop. However, the weft jersey structure is a single knit; the air spaces occur to the left and right sides of the yarns in the knit. The interlock, a double knit structure, contains additional air spaces between the face and back layers.

The prediction that an increase in moisture transport would result from an increase in the openness of the fabric structure is related to the diffusion mechanism. Various opinions regarding the importance of the diffusion mechanisms exist. Some authorities now suggest that the diffusion mechanism is of little importance, but also suggest that its importance increases when air currents are present.

Perhaps other moisture transport mechanisms influence moisture transport, since this research indicates that the interlock transports moisture significantly faster than the weft jersey structure.

Other possible mechanisms would include the absorption-desorption mechanism, capillary transport, and migration along the fiber's surface. Using the process of elimination, it appears that the only mechanism which would influence moisture transport due to variations in knit structure would be the capillary transport mechanism.

The absorption-desorption mechanism would be related to variations in fabric structure only if swelling of cotton reduced moisture transport. This would be more important for tightly structured fabric; the blocking factor is probably not important in relation to the relative openness of the two knit structures. Also, migration along the fiber's surface is probably not related to variations in fabric structure; it would be influenced more by changes in the fiber content.

However, capillary transport could influence the moisture transport due to variations in knit structures. Capillary transport could perhaps be increased in a slightly less open knit structure, such as the interlock. Perhaps capillary flow is accelerated when fabric has smaller or closer air spaces. The size and shape of the openings could be related to capillary flow. Capillary tubes can form between (1) the various fibers in the yarn, and (2) various yarns in the knit. It has been suggested that the amount of space between the yarns can influence moisture transport. However, no guidelines concerning the yarn spacing have been suggested.

Fiber Content or Fabric Structure

When researchers first became interested in studying the moisture transport properties of fabrics in relation to clothing comfort, the fiber content was considered the important fabric variable to examine. The role of the fiber content has throughout the history of the study of moisture transport received more examination than fabric structure or other fabric variables. However, more recently, researchers have begun to investigate the role of fabric structure on moisture transport properties of fabrics. However, research has been influenced by the absence of a standard moisture transport test method which replicates various use conditions.

Research findings regarding the role of two important fabric variables, fiber content and fabric structure, in moisture transport through fabric is still somewhat unclear. Knight (7), in one of the few recent studies which used knits, suggested that the fabric structure was a more important fabric variable than fiber content.

The third research hypothesis for this research stated that the fabric structure would be a more important fabric variable than fiber content in promoting moisture transport in fabrics. This prediction was based on the first two research hypotheses. The first research hypothesis predicted that no significant differences would occur in moisture transport due to fiber content. The research suggested that a statistically significant difference did exist between 100 percent cotton, the slowest transporter, and two fibers, 100 percent polyester and 50/50 percent cotton/polyester. The second research hypothesis stated that the jersey structure would allow more moisture transport than the interlock structure. The research findings indicated that the interlock structure allowed significantly more moisture transport than the weft jersey structure.

The analysis of the third research hypothesis was done by examining the results from the first two hypotheses. Therefore, this research suggested that both fabric variables, fiber content and fabric structure, were important in determining the rate of moisture transport. Neither fabric variable was shown to be more important than the other in all situations. It appears that in certain situations, the fabric structure may be more important than the fiber content, since differences occurred between both levels of the fabric structure whereas differences did not occur between all levels of the fiber content. For example, if the choice was between the use of 100 percent polyester or 50/50 percent cotton/polyester, the fiber content would not be important since no significant differences were found to exist between these two fibers. However, the fabric structure would still be an important fabric variable in determining the moisture transport properties of the knit.

Moisture Form

Most moisture transport research examined only vapor transport. It was considered desirable to replicate various use conditions during the moisture transport tests, one of which is frequently involved in the liquid moisture form or sweat. The liquid form might present a more severe test for a fabric due to an increased quantity and change in moisture form.

Moisture transport mechanisms differ for the vapor and liquid forms. Vapor transport uses only two moisture transport mechanisms: (1) diffusion, and (2) absorption-desorption which is limited to hydrophilic fibers. Liquid transport can utilize all or any combination of moisture transport mechanisms. Liquid form also includes vapor transport, since vapor is present in the air over the liquid film.

This research suggested that no significant differences exist in moisture transport between the vapor and liquid moisture forms. Although this research did not suggest significant differences between the two moisture forms, additional research on various fibers and fabrics is needed. Use of both moisture forms during moisture transport tests is recommended since no correlation was found between the two moisture forms. In addition, moisture form, a treatment variable, was a factor in several of the statistically significant interaction effects presented in Chapter 4.

Air Velocity

Although ambient air has been used in most laboratory research, variations in air velocity should be included. This research suggests that moisture transport tests using moderate air currents above the fabric's upper surface transport significantly more moisture than the tests performed in ambient air. The increase in moisture transport when moderate air currents are used is much greater than when ambient air currents are used. This increase in moisture transport would also increase the amount of evaporative cooling achieved during wear.

The transport mechanisms most likely to be involved in the increase would be the diffusion mechanism which must be increased with an increase in air currents. Mecheels (14) suggests that the diffusion mechanism is not important unless air currents are present. All knit structures used in this study were moderately open, which would probably allow the air currents to aid moisture transport. Air currents also aid moisture transport by removing the moist air and replacing it with less humid air.

Variations in air currents could also influence the point where evaporation of moisture occurs. Some authorities believe that evaporation generally occurs near the fabric's upper surface. However, if the fabric structure were somewhat open, air currents might cause evaporation to occur within the fabric structure or nearer the skin's surface. According to some authorities, the nearer evaporation occurs to the skin's surface, the greater the evaporative cooling effect is realized.

Interaction Effects

No previous research was found which determined whether interaction effects existed between fabric variables, i.e. fiber content and fabric structure. Previous research analyzed only the main effects. Interaction effects examine what possible effects the unique combination of variables had on results above the effects expected due to each variable alone.

This research design using four independent variables had potentially several interaction effects which included all possible combinations of the four variables. Due to the large number of possible interaction effects, no research hypotheses were formulated concerning expected interactions between the independent variables. Interaction effects examined whether the rate of moisture transport was due to the various combinations of variables. This research only determined whether interaction effects appeared statistically significant.

The first order interaction effects found statistically significant at the .05 level of significance included the following: fabric structure/air velocity, fiber content/

moisture form, and fiber content/air velocity. Three combinations of two variables were not found to be statistically significant: fiber content/fabric structure, fabric structure/moisture form, and moisture form/air velocity.

Most research built only fabric variables into the research design; hence only fabric variables were analyzed. This research examined treatment and fabric variables. Most research again did not analyze interaction effects. The fiber content/fabric structure combination was, of course, of special interest. However, no statistical significance was found for this combination of variables.

Three second order interaction effects were statistically significant. The following combinations of three variables created an effect in addition to that of what would be expected by a simple combination of the variables. The significant second order interactions included: (1) fabric structure/fiber content/moisture form, (2) fabric structure/fiber content/air velocity, and (3) fiber content/moisture form/air velocity.

Statistical analysis did not suggest that the third order interaction effect, which combined all independent variables, was significant.

Control

The four moisture transport tests in the series were performed using the selected knit fabrics. In addition, all four tests were performed without any fabric over the test area. This was designated as the control. Although it was not possible to statistically analyze the control, comments concerning the control are presented in this chapter. Generally, it is expected that more moisture is lost and more evaporative cooling occurs when the subject is unclothed. The control represents the unclothed subject.

The control did allow more moisture transport than all test fabric samples in the three following moisture transport tests: (1) vapor form/ambient air, (2) vapor form/moderate air currents, and (3) liquid form/ambient air. However, in the liquid form/ambient air moisture transport test, one test fabric transported more moisture than the control. The 50/50 percent cotton/polyester interlock fabric transported more moisture than the control. The other five test specimens transported less moisture than the control. It has been suggested that it is possible for more moisture transport to occur in some situations when the subject is clothed than when nude. However, no specification of situations was presented.

Suggestions for Additional Research

Most moisture transport tests used in previous research have used vapor form in ambient air. No previous research on knits examined the use of vapor and liquid moisture forms with and without moderate air currents. Additional research is needed to study the role of fiber content and fabric structure in moisture transport through knit fabrics.

Research designs should allow several independent variables, treatment and fabric, to be examined simultaneously. In addition, interaction effects between variables should be analyzed.

Additional research should examine new fiber developments such as the hollow fiber. New yarn structures should be examined to determine the role of various yarn factors in moisture transport. The use of spun yarn is increasing in knit fabrics. Spun yarn fabrics should be compared with fabrics using filament yarns. Moisture transport properties of knits produced from yarns made on the open-end system versus the regular spinning system should be compared. The influence of new finishes on the market which claim to improve the wicking properties of polyester fabrics should be compared to regular heat-set polyester.

More research is needed to develop and adopt standard test methods for measuring moisture transport properties of textile fabrics. Additional test methods should be developed which allow quantitative determination of various transport mechanisms or processes. Statistical analysis examined the results of test series. Each test in the moisture transport test series carried an equal amount of weight. In some situations it might be desirable to weight specific tests from the series differently. For example, in evaluating fabric for use in active sportswear, such as tennis wear, the liquid form/moderate air test might be weighted more heavily.

CORRELATIONS

Moisture Transport Tests in Series

No Spearman rho rank order correlation of individual tests in the moisture transport test series were suggested. Therefore, use of all four tests in the moisture transport test series is recommended to more fully replicate use conditions. The test most frequently used in research is the control dish method based on a gravimetric method. It measures only vapor form in ambient air. The test series replicates two moisture forms, vapor and liquid, and two levels of air currents, ambient air and moderate air currents.

The Spearman rho correlation suggests that all four tests represent or measure different use situations. This research suggested that fabrics transport moisture differently during the various tests in the moisture transport test series. The test series is not too difficult, time-consuming, or costly to perform. Use of the same basic apparatus, with a slight change in specimen mounting procedure and assembly, simplifies the change from the vapor to liquid moisture form.

Correlation of Moisture Transport Tests and Basic Fabric Properties

No basic fabric properties or set of basic fabric properties were found to correlate with all tests in the moisture transport test series. Therefore, use of the test series is recommended over use of a series of indicators which may measure some aspects of moisture transport.

Vertical wicking is frequently used as an indicator. Since the vertical wicking test uses liquid and is performed in ambient air, the moisture transport test most expected to correlate with wicking would be the liquid form/ambient air. A weak trend, .20 level of significance, was suggested.

The time for wicking test measurement was five minutes. This short time could perhaps be too brief to allow various transport mechanisms or processes to occur. The moisture transport mechanisms most likely to be used in the vertical wicking test include migration along the fiber's surface, capillary transport, and absorption-desorption.

The drop absorption-complete penetration test involved measuring the time required for a single drop of water to be completely absorbed by the fabric. It must be performed in ambient air. Since it uses liquid, it would be expected that this test would be more likely to show a relationship with the liquid form/ambient air test from the moisture transport test series. A correlation indicating a weak trend, .20 level of significance, was suggested between drop absorption and vapor form/moderate air current moisture transport test from the test series.

A strong Spearman rho rank order correlation was shown between the percent moisture regain and the liquid form/moderate air currents test from the moisture transport test series. The most logical expectation would be that the percent moisture regain would be related to the liquid form/ambient air currents test from the moisture transport test series. The percent of moisture regain would be influenced mainly by the ability of the fiber content to absorb vapor from the air, which related to the fiber absorption-desorption mechanism.

The percent saturation moisture regain is frequently used as an indicator. It is related to the total fabric absorption. Total absorption is related both to fiber content and fabric structure. However, the association is with moisture absorption capacity and not moisture transport. The percent saturation moisture regain did not suggest any relationship with any tests in the moisture transport test series.

The percent of moisture imbibition after centrifugation has also been used as an indicator of a fabric's moisture transport properties. This test is quick and simple to perform. It would be expected to show a relationship with the liquid form/ambient air moisture transport test. However, a negative correlation was suggested between the percent of moisture imbibition and the vapor form/

moderate air currents moisture transport test method. No obvious explanation for the correlation is apparent.

Most of the moisture remaining in the fabric after centrifugation is in the fiber which would tend to be associated with the mechanism of fiber absorption-desorption.

Early opinions suggest a relationship of air permeability and moisture transport. More recently some authorities say that moisture and air are transported differently; therefore, a relationship would not necessarily be expected. They say that air cannot go through the fiber but that vapor can. However, in synthetic fabrics, vapor does not go through the fiber. However, a difference in mechanisms might exist. Moisture can travel through synthetic fabrics by migration along the fiber's surface or by a capillary transport. However, air movement is mainly by diffusion.

Air permeability is still used as an indicator, perhaps partly because standard test equipment and test method has been adopted. The possibility of a relationship between air permeability and the moisture transport tests should be examined. Most knits, including those used in this study, are not as tightly structured as many of the tightly woven synthetics. The moderate openness of the knits made it conceivable that air permeability could relate to several of the moisture transport tests. Air permeability would be expected to most strongly show a relationship to tests using moderate air currents.

The Spearman rho correlation suggested that a trend, .10 level of significance, existed between air permeability and two moisture transport tests, vapor form/moderate air currents and liquid form/moderate air currents. Both of the tests which suggested a relationship did use the moderate air currents.

Fabric thickness has been used as an indicator of many thermal comfort factors, including moisture transport, insulation, and convection. Some suggest that a thicker fabric will slow moisture transport by reducing diffusion. Others suggest that a thicker fabric would allow the fabric to pick up more moisture initially without feeling wet.

Spearman rho correlation suggested a weak trend, .20 level of significance, between fabric thickness and liquid form/moderate air currents. Perhaps more moisture is picked up by the thicker fabric; the air currents then aid in the removal of the moisture.

In addition, a fabric's weight has been used as an indicator of moisture transport properties. This research suggested a correlation between the fabric's weight and the liquid form/moderate air currents.

Correlations Between Basic Fabric Properties

No hypotheses were formulated for possible correlations which might occur between the various basic fabric properties frequently used as indicators of moisture transport. In the absence of a standard moisture transport test method, the researcher frequently uses several of the basic fabric property tests in conjunction to indicate a fabric's moisture transport abilities. The possibility that some of these tests were not good indicators of moisture transport during various use situations was previously considered. It is also possible that some of the basic fabric property tests correlate with one another.

The vertical wicking tests showed a correlation between the warp and the weft direction of this test. Due to differences in the warp and weft direction, this was not expected. In the warp direction the wales are parallel to the specimen's length; the courses are perpendicular. The direction of the wales and courses are reversed in the weft direction. It was thought that possibly the direction of the wales and courses could influence the capillary transport mechanism; apparently, capable of moisture transport in both directions.

The drop absorption test, complete penetration, was performed with a water drop hitting both the face and the back sides of the fabric. It was thought that for jersey fabrics, which have wales on the face and courses on the back, complete penetration might be influenced because of possible differences in capillary transport and migration along the fiber's surface. However, this was not found to be true since a perfect correlation existed between drop absorption, complete penetration, for the face and back sides of the knit fabrics.

In addition, an unexpected correlation trend was suggested between drop absorption and air permeability. This suggests that the fabric with high air permeability took a longer time for complete penetration of drop absorption.

Two other tests suggested negative correlation trends between drop absorption and the percent saturation moisture regain and the percent moisture imbibition. This implies that the lower the percent saturation regain or the percent moisture imbibition, the longer it took for the complete penetration of the water drop to occur. This suggests an association with the fiber absorption-desorption transport mechanism.

The percent moisture regain suggests a negative correlation with air permeability. This suggests that the lower the percent of moisture regain, the higher the air permeability, and vice versa. A possible correlation was suggested between the percent of moisture regain and the fabric weight, which implies that a lighter weight fabric will have a lower moisture regain.

The percent saturation moisture regain suggests a correlation trend with the fabric's thickness. A thicker fabric would have a higher saturation regain. Perhaps this implies that more fiber surface, internal or external, is available for the water to attach itself. The negative correlation trend between the percent saturation moisture regain and drop absorption was previously discussed.

The percent of moisture imbibition suggested a negative correlation with two other fabric property tests, air permeability and drop absorption. This suggests that the higher the air permeability, the lower the percent of moisture imbibed after centrifugation.

Air permeability suggests a correlation with the percent of moisture regain and a trend with both drop absorption and negatively with the percent of moisture imbibition. These correlations were previously discussed.

Fabric thickness suggested a negative trend with drop absorption and percent saturation regain; these correlations were previously discussed. Fabric weight also showed a correlation with the percent of moisture regain and air permeability, as previously discussed.

Correlation of Various Basic Fabric Property Tests

Data concerning the basic fabric property tests were presented in the correlation section of Chapter 4. Additional data and comments related to the results of basic fabric property tests performed on the selected knit fabrics will be presented in this chapter. Several of the basic fabric property tests are used to estimate the moisture transport ability of fabrics; however, most of the research was on woven fabrics.

Vertical wicking tests. Data for the five-minute vertical wicking tests in the warp and filling directions are in the correlation section of Chapter 4. Vertical wicking tests using the bias direction were developed and performed to enable examination of the wicking mechanism. All vertical wicking tests were recorded at one and five minutes. Table 54 presents complete data for the vertical wicking tests.

The range of distances for vertical wicking in the warp and filling directions for one minute was 1-27 mm (0-11"). The range for the five-minute test in the warp direction was 5-41 mm (2-16") and in the weft direction 9-43 mm (4-17"). All fabric samples were ranked in the same sequence for the five-minute vertical wicking test for the warp and filling directions.

In general, cotton wicked the most, followed by polyester, then cotton/polyester. This appears to be the reverse of the results obtained in the moisture transport test series. Perhaps this short time for the test would influence the results. Perhaps in the short test time of the vertical wicking test the measurement is more related to the fiber absorption-desorption mechanism. From the drop absorption and wicking tests, it appears that some fabric surfaces do not wet out readily; this adds to the time it takes for moisture transport to start. It would be interesting to try this test increasing the length of the test specimen and increasing the test time period to perhaps fifteen minutes or one-half hour. Vertical wicking appeared to be related to fiber content and fabric structure. The

Table 54

Vertical Wicking Tests

Fiber Content	Fabric Structure	Warp				Filling				Bias			
		S.I.		U.S.		S.I.		U.S.		S.I.		U.S.	
		1	5	1	5	1	5	1	5	1	5	1	5
		(min)		(min)		(min)		(min)		(min)		(min)	
C	J	20	41	8	16	23	39	9	16	26	44	10	17
C	I	27	41	11	16	27	43	11	17	23	33	9	13
C/P	J	1	16	1	6	1	12	0	5	1	16	0	6
C/P	I	1	5	0	2	0	9	0	4	1	5	0	2
P	J	9	18	3	7	5	23	2	9	15	37	6	15
P	I	18	28	7	11	17	32	7	13	25	36	10	14

CODE: C = 100% cotton; C/P = 50/50% cotton/polyester; P = 100% polyester; J = jersey; I = interlock.

jersey structure wicked a higher distance than the interlock structure for all fiber contents.

The test in the bias direction was used to observe the moisture transport to determine whether either the wales or courses were more important in moisture transport. For the bias direction in the jersey knits the wales went to one side and the courses in the other; hence it was more visible if transport occurred in one direction more than the other. In general, it did not appear that there was much difference in transport along the wales and courses. Perhaps this indicates that the fabric's physical structure, the wales versus the courses, appeared to be less important than the fiber content for this test. This would also relate to the small differences found in moisture transport between the warp and filling direction. If moisture will wick equally well along the wales as it does along the courses, no differences would be expected in the warp and filling directions.

The observation of bias wicking provided the following comments for various knits. In the polyester interlock knit, the wicking appeared to travel up the wales, then across the courses in the test performed in the warp direction. It was difficult to obtain an accurate reading for the cotton interlocks because the moisture traveled up the inside along the courses of the double structure. The inside became moist before the moisture appeared on the outside.

It was difficult to immerse cotton/polyester jersey into the water. Apparently the surface of this fabric was not very wettable; in addition, the meniscus pointed downward instead of upward. The wicking properties of this fabric were perhaps influenced by the durable press resin finish. The polyester/cotton interlock was also difficult to immerse in the water.

The polyester jersey wicking occurred mainly in the course direction. Additional tests should be performed on knits in the bias direction to observe wicking ability along the wales and courses.

Drop absorption. The drop absorption tests measured the initial and complete penetration for both the face and back sides of the fabrics. Only the complete penetration drop absorption tests were analyzed in the correlation tests. The face and back sides for the complete penetration showed a very highly significant correlation. Complete data for the drop penetration tests are presented in Table 55. Instantaneous complete wetting was recorded as one second.

The time range for initial penetration for the face of the fabric was 1-122 seconds and for complete penetration the range was 1-900 seconds. For the back side of the fabric, the time range for initial penetration was 1-273 seconds and for the back side the range was 1-628 seconds.

The range for initial penetration for the face was 1-122 seconds and for complete penetration, 1-900 seconds.

The range for the initial penetration on the back side was 1-273 seconds and for complete penetration it was 1-628 seconds.

Table 55

Drop Penetration Tests

Fiber Content	Fabric Structure	Face		Back	
		Initial (sec)	Complete (sec)	Initial (sec)	Complete (sec)
C	J	1*	1	1	1
C	I	1	1	1	1
C/P	J	122	337	273	438
C/P	I	51	138	49	138
P	J	122	900	13	628
P	I	1	300	9	357

CODE: C = 100% cotton; C/P = 50/50% cotton/polyester; P = 100% polyester; J = jersey; I = interlock.

*Instantaneous complete penetration recorded as 1 second.

In addition, closer examination during this test with the aid of a magnifying glass allowed additional observations concerning moisture transport from initial to complete penetration. After the initial wetting, a round reservoir remained which served to feed the surrounding fibers and/or yarns. An even spreading from the reservoir probably indicated that wicking occurred along both the courses and wales. Wicking in an uneven manner from the reservoir generally indicated that wicking tended to occur more either along the wales or courses. This was determined by direct observation with a magnifying glass during the test. After complete penetration occurred, the moist area was outlined to examine the transport direction.

Differences were not so great between the face and the back as originally anticipated. It was thought that if wicking occurred mainly along the courses, which are located on the technical back side of the fabric, more wicking would occur on the back side. Observation with the magnifying glass suggested that the water bead would often not wet out the side where the initial contact occurred. The water bead sometimes went through the space between the yarns to the other side before transport actually started. This occurred during the cotton/polyester jersey test.

The cotton interlock fabric had similar construction and penetration characteristics for the face and back sides of the fabric. The shape of the outline after complete penetration was almost circular, which indicates that wicking occurred along both the course and wales.

The water drop on the cotton/polyester jersey fabric beaded up indicating low fabric surface wettability. The moisture traveled in an uneven manner, which could be related to the resin finish. The scouring procedure should have eliminated any unevenness of excess finishes. The polyester fabrics started wicking quickly, but it took a long time for complete penetration to occur. Examination with the magnifying glass showed a water film on the fabric's surface.

<u>Moisture regain and retention</u>. Moisture regain and retention tests performed included (1) percent moisture regain, (2) percent moisture saturation regain, and (3) percent moisture imbibition after centrifugation. Table 56 presents data for all three tests. Of the three tests, the percent moisture regain were the lowest percentages, which indicates only the amount of moisture the fiber picked up from the environment. The next highest readings were from the percent moisture imbibition. The fabrics were immersed in water, then centrifuged. The amount of moisture retained is generally believed to be held in the fiber. The highest percentages were from the percent saturation regain which indicated the total amount of water the fabric could hold which included the fiber content and fabric structure.

The range of percentages for moisture regain were from 1.36 to 8.30. Generally, polyester was the lowest, followed by cotton and cotton polyester. In fabrics containing cotton, the interlock fabric structures gained more moisture.

The range for the percentage of moisture imbibition was from 21.78 to 76.23. This range is much higher than the percentages of moisture regain. The two polyester fabrics were still the lowest, followed by cotton/polyester. Cotton fabrics had the highest percentages of moisture imbibition. For polyester and cotton, the interlock structures had a higher percentage of moisture imbibition.

The range of moisture regain was 164.7 to 289.23 percent. The single knits had the lowest percentages of regain. Cotton interlock had the highest percent of moisture saturation regain. The polyester jersey was the lowest, but the polyester interlock was next to the highest.

Table 56

Moisture Regain and Retention Tests

Fiber Content	Fabric Structure	Moisture Regain %	Moisture Saturation %	Moisture Imbibition %
C	J	6.51	231.54	64.84
C	I	7.76	289.23	76.23
C/P	J	7.36	172.95	54.16
C/P	I	8.30	277.07	50.94
P	J	2.50	164.70	21.78
P	I	1.36	283.20	24.14

CODE: C = 100% cotton; C/P = 50/50% cotton/polyester; P = 100% polyester; J = jersey; I = interlock.

<u>Air permeability</u>. Table 39 in Chapter 4 presented the data for the air permeability tests. The range for this test was 75.44 - 311 $cm^3/cm^2/sec$ (148.5 - 613 $ft^3/ft^2/min$). Cotton fabrics had the lowest values, followed by cotton/polyester. Polyester had much higher air permeability values. The staple yarns of the cotton and cotton/polyester have more surface hairiness than filament polyesters which

could reduce air permeability. Single knits containing cotton had higher values than interlocks containing cotton. However, polyester single and interlock knits had very similar values.

Thickness. Table 41 in Chapter 4 gives data for the fabric thickness tests. The range for fabric thicknesses was 0.53 - 0.81 mm (0.021 - 0.032"). The thinnest fabric was the polyester jersey; the thickest was the cotton/polyester interlock fabric.

Thickness appeared to be more related to the fabric structure than fiber content. The single jerseys tended to be thinner than the double structured interlocks. The range for jersey knits was 0.53 - 0.66 mm (0.021 - 0.026 in). The range for the interlock fabrics was 0.71 - 0.81 mm (0.028 - 0.032 in).

Weight. Table 43 in Chapter 4 gives the values for fabric weight. The range was 130 - 200 g/m^2 (4 - 6 oz/yd^2). Polyester fabrics were the lightest; the other fabrics were approximately the same, except for the cotton jersey which was slightly less. The low values for polyester relate to the fiber content. Thickness and weight were also discussed under fabric descriptive properties.

Chapter 6

SUMMARY, DISCUSSION, AND RECOMMENDATIONS

SUMMARY

This research measured moisture transport properties of selected knit fabrics. Two fabric variables, fiber content and fabric structure, were examined using apparatus designed to measure vapor and liquid transport. The fibers used in this research included 100 percent cotton with a urea formaldehyde finish, 100 percent textured filament polyester, and 50/50 percent cotton/polyester treated with a durable press resin. The knit structures used were a single weft jersey structure and a weft interlock which represented a double knit structure.

Two major fabric variables associated with moisture transport properties of fabrics included the fiber and the fabric structure. Research which examined moisture transport properties of hydrophobic and hydrophilic fabrics remained confusing. Much of the previous research suggested that cotton fabrics have better moisture transport properties, since the fiber absorbed more moisture. More recent research suggested that polyester fabrics could transport more moisture than predicted due to the wicking mechanism. Moisture transport properties of blended fabrics has not been carefully examined. In addition, little research has used knit fabric structures; most moisture transport research has examined moisture transport properties of woven fabrics. Knight et al. (7, 8) did find significant differences in moisture transport properties of two types of single weft knits. No research has compared moisture transport properties of single and double weft knit structures. Research methodology makes it possible to examine two fabric variables simultaneously; hence this research was concerned with moisture transport properties related to both fiber and fabric structure.

No standard moisture transport test method for apparel fabrics has been adopted in the United States. In Canada, a standard method for determining vapor transport in ambient air has been adopted. In the absence of a standard test method, several fabric property tests, such as vertical wicking, drop absorption, and moisture regain values, have been used frequently as tests to indicate moisture transport properties of fabrics. Results tend to vary with the type of test or combination of tests used in the research. The comfort factor is becoming a more important concern to industry and the consumer; hence the need for a standardized test which is not too difficult to perform and interpret.

The specific objectives of this research were the following:

1. To design apparatus and procedures to measure moisture transport properties of apparel fabrics during various use conditions;
2. To measure moisture transport properties of selected knit fabrics in order to examine two fabric variables, fiber content and fabric structure, and two treatment variables, air velocity and moisture form; and
3. To perform several other basic fabric property tests such as vertical wicking and drop absorption to determine whether a relationship existed between these tests and the researcher developed test methods.

Test Apparatus

Since no standard moisture transport test method was available for apparel fabrics, a major portion of this research involved the development of test apparatus and procedures. The researcher wanted to design apparatus which would allow the determination of both vapor and liquid moisture forms to represent various use situations. In addition, the apparatus and procedures were not to be too difficult to perform or interpret in order to promote use in industry to determine fabrics which would not sufficiently transport moisture. The following series of tests were developed to more fully replicate use conditions:

1. Vapor form/ambient air currents
2. Vapor form/moderate air currents
3. Liquid form/ambient air currents
4. Liquid form/moderate air currents.

Tests were performed at 37°C. (98.6°F.) and 30 percent relative humidity to replicate conditions in a hot, dry environment.

The vapor transport test method represented a modification of Rees's volumetric method in which the quantity of water which was evaporated from the moisture test area was measured by an external capillary tube. The rate of moisture transport, a direct unit, was expressed in grams of water loss per square centimeter of fabric for a twenty-four hour time period. The same basic test apparatus was used for each test in the series.

Fabric test specimens were mounted in a plastic hoop and placed over the upper surface of the water filled vessel. The test specimens for vapor tests were placed 1.5 centimeters from the water level of the vessel. The liquid test method used the same basic apparatus; however, the specimen mounting procedure for liquid tests used the fabric test specimen in contact with a moist wicking polyurethane foam sponge which was inserted in the plastic hoop.

The procedures gave data which were not entirely reproducible for knit fabrics from the same lot. Although refinement in technique concerning air flow and mounting of the fabric specimen on the polyurethane foam were suggested, certain of the differences were due to variations within the knit fabrics as shown from the results of the wicking and drop absorption tests. The variations in knit structures arose from the special problem of knit tensions and unequal application of resin finishes.

DISCUSSION

Results of Individual Tests in the Moisture Transport Test Series

Vapor form/ambient air currents. The 50/50 percent cotton/polyester jersey was the fastest moisture transporter. The 100 percent cotton interlock knit was the next fastest moisture transporter. The slowest transport occurred in the 100 percent polyester jersey, 100 percent cotton jersey, and the 50/50 percent cotton/polyester interlock knit. Little moisture transport occurred for this test which used vapor form/ambient air.

Vapor form/moderate air currents. The 100 percent polyester interlock was the fabric which allowed the most moisture transport for vapor form with moderate air currents. The second fastest moisture transporter was the 100 percent polyester jersey. The surface smoothness of the textured filament polyester fabric allowed the air to enter the fabric structure more readily to increase moisture transport.

The 50/50 percent cotton/polyester fiber was the next fastest fiber transporter; cotton fabrics were the slowest transporters. Cotton fibers swell thus reducing the entry of air which aids in the removal of moisture. In addition, cotton staple fibers also have a barrier effect because of the insulating air spaces resulting from the surface hairiness of cotton staples.

Fiber related variables appeared more important than variations in knit fabric structure for the moisture transport test using vapor form and moderate air currents.

Liquid form/ambient air currents. Little moisture transport occurred when ambient air was used in the test procedure. The 50/50 percent cotton/polyester interlock knit structure was the fastest moisture transporter. The 50/50 percent cotton/polyester blend fabrics probably allowed more moisture transport mechanisms to function during liquid transport. Cotton transported moisture by absorption inside the fiber; whereas polyester transported liquid by wicking.

In addition, the resin finish on the blend prevented the fiber from swelling excessively in the blended fabric. However, examination of cotton/polyester blend fabrics does not represent an arithmetic mean, since the resin finish reduced the swelling of the cotton knit.

Liquid form/moderate air currents. The 50/50 percent cotton/polyester was the fastest moisture transporter followed by cotton fabrics. Polyester fabrics were the slowest transporters. Moisture transport appeared to be influenced more by fiber related variables than by the fabric or knit structure.

The 50/50 percent cotton/polyester fabrics used the principle of increasing the number of transport mechanisms as did the liquid transport test in ambient air. Liquid moisture transport was greatly aided by the use of moderate air currents over the upper surface of the fabric.

The polyester fabrics were the slowest moisture transporters in the liquid form/moderate air current test, because it was more difficult for the filament polyester fibers to pick up liquid from the moisture test area than for fabrics made from staple fibers. The staple fiber fabrics had better initial moisture pick-up due to the increased number of contact points on the back surface of the fabric.

Variations in air currents appeared to be an important treatment variable. Air currents greatly increased moisture transport over the tests performed in ambient air. Use of ambient air did not allow as much moisture transport as the tests which used air currents.

ANOVA Results from the Moisture Transport Test Series

The research design for the moisture transport test series allowed for the examination of four variables; two fabric variables, fiber content and fabric structure, and two treatment variables, air velocity and moisture form, were studied. The examination of the entire moisture transport test series using four-way analysis of variance suggested that fiber and fabric structure were both important fabric variables in moisture transport.

Fiber related variables included differences in moisture transport mechanisms for the various fibers such as the wicking mechanism for polyester and the fiber absorption mechanism for cotton. In addition, the fabric surface smoothness or hairiness influenced the initial moisture pick-up. This was shown in the case of staple fiber fabrics versus filament fiber fabrics. The swelling of cotton due to fiber absorption as well as the reduction of swelling of cotton in resin finished blended fabrics influenced moisture transport.

Variations in fabric structure related to variations in the basic knit structure, the number of wales per inch, the size and shape of air spaces, fabric thickness, evenness of the knit, and the nature of the surface as related to its classification as a single or double weft knit structure.

Fiber content. The 50/50 percent cotton/polyester and the 100 percent polyester fabrics transported moisture significantly faster than cotton. The Newman-Keuls post-hoc statistical analysis suggested that no statistically significant differences in moisture transport existed between the 50/50 percent cotton/polyester fabrics and the 100 percent polyester fabrics.

Fabric structure. The interlock fabric structure transported moisture significantly faster than the jersey fabrics in the complete moisture transport test series. Both fiber related variables and fabric structure were suggested to be important fabric variables to consider when engineering fabrics with good moisture properties. Analysis of variance did not suggest that there was any significant first-order interaction effects between the two fabric variables, fiber content and fabric structure.

Treatment variables, air velocity and moisture form. The use of moderate air currents in the test procedure greatly increased moisture transport in knit fabrics over the use of tests using ambient air currents. Variations in moisture form, liquid and vapor forms, were not shown to be statistically significant.

Interaction effects. First-order interaction effects significant at the .05 level included fabric structure/air velocity, fiber content/moisture form, and fiber content/air velocity. Second-order interaction effects significant at the .05 level were fabric structure/fiber content/moisture form, fabric structure/fiber content/air velocity, and fiber content/moisture form/air velocity.

Correlations

Correlation between moisture transport tests.

Individual tests in the moisture transport test series were analyzed to determine whether any correlations existed between individual tests in the moisture transport test series which used either the same moisture form or air velocity. No Spearman rho rank-order correlations were suggested between any of the individual tests in the moisture transport test series using the same moisture form or air velocity.

Correlation between tests in the moisture transport test series and tests used as indicators.

No basic fabric property tests or set of basic fabric property tests were found which suggested a significant correlation with the entire moisture transport test series. Use of the moisture transport test series was recommended over the use of a series of quick indicators such as vertical wicking and drop absorption in order to more fully replicate various use conditions.

RECOMMENDATIONS

Since comfort is becoming a more important factor to both the consumer and producer of apparel, more attention should be focused toward the adoption of a standard test method for determination of moisture transport properties of apparel fabrics. The test should not be too difficult to perform and interpret. The test should be used to determine fabrics which would not allow sufficient moisture transport.

Additional research is needed to perfect and perhaps modify the moisture transport test series developed in this research. Additional study could determine whether all four of the tests in the series are necessary or whether it would be possible to perform one or two tests in order to determine fabrics with poor transport properties. In addition, a procedure for evaluating the evenness of knit fabric structure and the evenness of resin applications could be used. Development of a special housing for the fan used to create air currents could be implemented.

Moisture transport properties of other fibers and fabric structures including woven fabrics should be measured using the moisture transport test series. In addition, polyester fabrics treated with the various newly developed wicking finishes should be compared with regular polyester.

REFERENCES

1. Newburgh, L. H. (ed.). Physiology of Heat Regulation. Philadelphia: W. B. Saunders Co., 1949.

2. Leach, L. L. "Fibres, Fabrics, and Body Comfort," Canadian Textile Journal, 74:9, May 3, 1957, 59-65.

3. Fourt, Lyman, and Hollies, Norman R. S. Clothing: Comfort and Function. New York: Marcel Dekker, Inc., 1970.

4. Renbourn, E. T. Materials and Clothing in Health and Disease. London: H. K. Lewis and Co., 1972.

5. Kemp, Sheila. "The Consumer's Requirements for Comfort," Textiles for Comfort. Third Shirley International Seminar, Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, 1971.

6. Anon. "Cotton Advertisement," California Men's Stylist, 37:6, June, 1973, 8-9.

7. Knight, Billy Arnold. "The Effect of Cotton and Synthetic Fiber Blends on the Moisture Responses of Basic Knit Structures." Unpublished Master's thesis, North Carolina State University, Raleigh, 1969.

8. Knight, B. A., Hersh, S. P., and Brown, P. "Moisture Characteristics of Some Knit Fabrics Made from Blend Yarns," Textile Research Journal, 40:11, November, 1970, 843-851.

9. Greenwood, Dr. K. "The Language of Comfort," Textiles for Comfort. Third Shirley International Seminar, Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, 1971.

10. Canadian Government Specifications Board, Extract from CGSB Standard 4-GP-2, Canadian Standard Textile Test Method, Method 49-1962, Resistance of Materials to Water Vapor Diffusion.

11. American Society for Testing and Materials. 1970 Annual Book of ASTM Standards, Part 24, Textile Materials--Yarns, Fabrics, General Methods. Philadelphia: ASTM, 1970.

12. Reichman, Charles (ed.). Knitting Dictionary. New York: National Knitting Outerwear Association, 1974.

13. Brown, Peter. Knitting Principles. Burlington, N.C.: Burlington Printing Services Co., 1972.

14. Mecheels, J. "Concomitant Heat and Moisture Transmission Properties of Clothing," Textiles for Comfort. Third Shirley International Seminar, Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, 1971.

15. Lennox-Kerr, Peter. "Micro-climate--Is It Jabberwocky?" Textile Industries, 135:2, February, 1971, 75-80, 82.

16. Dichter, Ernest. "Love That Fiber!" American Fabrics, 57, Summer, 1962, 82-84.

17. Dichter, Ernest. "The World Customer," American Fabrics, #60, Spring, 1963, 88-91.

18. Dichter, Ernest. "Needed for the Seventies: A Gourmet Approach to Fibers and Fabrics," American Fabrics, #85, Winter, 1969-70, 69-70.

19. Anon. "The Elements of Ordinary Clothing Comfort," Sources and Resources, 1973/4, 10-11.

20. McNall, P. E., Jr., Jaax, J., Rohles, F. H., Nevins, R. G., and Springer, W. "Thermal Comfort (Thermally Neutral) Conditions for Three Levels of Activity," ASHRAE Transactions, V73, pt. 1, 1967, pp. I.3.1-I.3.14.

21. Rohles, F. H., Jr. "The Modal Comfort Envelope: A New Approach Toward Defining the Thermal Environment in Which Sedentary Man is Comfortable," ASHRAE Transactions, V76, pt. 2, 1970, pp. 308-314.

22. Rohles, Frederick H., Jr. "The Revised Modal Comfort Envelope," ASHRAE Transactions, 79:2, 1973, 52-59.

23. Ghosh, R. C. "Comfort of Clothing," Silk and Rayon Industries of India, 15:3, March, 1972, 114-116.

24. Ogden, L. W., and Rees, W. H. "Measurement of Temperature and Relative Humidity on the Skin and Clothing of a Human Subject," Journal of the Textile Institute Transactions, 38:11, November, 1947, T371-386.

25. Morris, G. J. "Thermal Properties of Textile Materials," Journal of the Textile Institute, 44, 1953, T449-476.

26. Behmann, F. W., and Meissner, H. D. "Movement of Water in Wool--1. Experimental Determination of the Coefficient of Vaporous and Non-Vaporous Moisture Conduction," Journal of the Textile Institute, 55:3, March, 1964, T205-213.

27. Whelan, Margaret E., MacHattie, Lloyd E., Goodings, A. C., and Turl, L. H. "The Diffusion of Water Vapor Through Laminae with Particular Reference to Textile Fabrics, Part III: The Resistance of Fabrics to the Passage of Water Vapor by Diffusion," Textile Research Journal, 25:3, March, 1955, 211-223.

28. Mecheels, Jurgen H., Demeler, Renate H., and Kachel, Eberhard. "Moisture Transfer Through Chemically Treated Cotton Fabrics," Textile Research Journal, 36:4, April, 1966, 375-384.

29. Goldman, Ralph F. "Clothing Design for Comfort and Work Performance in Extreme Thermal Environments," Textiles for Comfort. Third Shirley International Seminar, Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, 1971.

30. Anon. "Terms Related to Texturing," American Fabrics, #87, Summer, 1970, 70.

31. Mark, H., Wooding, Norman S., and Atlas, Sheldon M. Chemical Aftertreatment of Textiles. New York: Wiley-Interscience, 1971.

32. Anon. "Some Comfort Aspects of High Percentage Cotton Blends," Sources and Resources, 1973/6, 9-11.

33. Black, C. P., and Matthew, J. A. "The Physical Properties of Fabrics in Relation to Clothing, Part I--A Review of the Literature," Journal of the Textile Institute Transactions, June, 1934, T197-224.

34. Black, C. P., and Matthew, J. A. "The Physical Properties of Fabrics in Relation to Clothing, Part II--Water Vapour Permeability of Fabrics," Journal of the Textile Institute Transactions, June, 1934, T225-240.

35. Mecheels, Jurgen. "Physiological Properties of Knitgoods," Hosiery Times, 38, January, 1965, 73-83.

36. Anon. "The Physiological Properties of Wool Clothing, Part 1," Wool Science Review, #21, August, 1962, 40-50.

37. Anon. "The Physiological Properties of Wool Clothing, Part 2," Wool Science Review, #22, March, 1963, 39-52.

38. Anon. "The Physiological Properties of Wool Clothing, Part 3," Wool Science Review, #23, July, 1963, 1-12.

39. Peirce, F. T. "Geometrical Principles Applicable to the Design of Functional Fabrics," Textile Research Journal, VXVII:3, March, 1947, 123-146.

40. Textile Institute and Society of Dyers and Colorists, Review of Textile Progress, V13, 1961, 46-47.

41. Asimov, Isaac. Understanding Physics. VI. Motion, Sound, Heat. New York: Walker and Co., 1966.

42. Winch, Allen R. "Theoretical Analysis of Rate of Liquid Absorption by Capillary Absorbing Media," Textile Research Journal, 29:3, March, 1959, 193-199.

43. Buras, Edmund M., Jr., Goldthwait, Charles F., and Kraemer, Rita M. "Measurement and Theory of Absorbency of Cotton Fabrics," Textile Research Journal, 20:4, April, 1950, 239-248.

44. Hardy, H. B., Jr., Ballou, J. W., and Wetmore, O. C. "Prediction of Equilibrium, Thermal Comfort Form, Physical Data on Fabrics," Textile Research Journal, 23:1, January, 1953, 1-10.

45. Gagge, A. P., Winslow, C. E. A., and Herrington, L. P. "The Influence of Clothing on the Physiological Reactions of the Human Body to Varying Environmental Temperatures," American Journal of Physiology, 124:1, October, 1938, 30-50.

46. Rothman, Stephen. Physiology and Biochemistry of the Skin. Chicago: University of Chicago Press, 1954.

47. Brinckerhoff, Richard F., Cross, Judson B., and Lazarus, Arthur. Exploring Physics. 2nd ed. New York: Harcourt, Brace and World, Inc., 1959.

48. Gregory, James. "The Transference of Moisture Through Fabrics," Journal of the Textile Institute, 21, 1930, T66-84.

49. Mecheels, Jurgen. "Physiolcgical Wearing Properties of Knitted Fabrics," Knitted Outerwear Times, 34:25, February 8, 1965, 25, 73, 75, 76, 81.

50. Vokac, Z., Kopke, V., and Keul, P. "Assessment and Analysis of the Bellows Ventilation of Clothing," Textile Research Journal, 43:8, August, 1973, 474-482.

51. Handbook of Human Engineering Data for Design Engineers. Nav Exos p-643, Tufts College. Project Designation NR-783-001. SDC Human Engineering Project 20-G-1, December, 1949.

52. Study of the Thermal Processes for Man-in-Space. NASA Contractor Report, prepared by Airesearch Manufacturing Co., Los Angeles. Contract No. NASW-1015. Washington: NASA, 1965.

53. Winslow, C. E. A., Herrington, L. P., and Gagge, A. P. "Physiological Reactions of the Human Body to Varying Environmental Temperatures," American Journal of Physiology, 120:1, September 1, 1937, 1-22.

54. Brouha, Lucien, Smith, P. E., Jr., and Maxfield, Mary E. "Man and His Thermal Environment," The Industrial Worker, 82:6, June, 1960, 57-59.

55. Rawson, Robert, and Randall, Walter C. "Vascular and Sweating Responses to Regional Heating of the Body Surface," Journal of Applied Physiology, 16:6, November, 1961, 1006-1010.

56. Hendler, Edwin, and Hardy, James D. "Man and His Thermal Environment," Mechanical Engineering, 81:8, August, 1959, 69-70.

57. Dill, D. B., Adolph, E. F., and Wilher, C. G. (eds.). Handbook of Physiology. Section 4, Adaptation to the Environment, pp. 27-35. Washington: American Physiological Society, 1964.

58. Vokac, A., Kopke, V., and Keul P. "Evaluation of the Properties and Clothing Comfort of the Scandinavian Ski Dress in Wear Trials," Textile Research Journal, 42:2, February, 1972, 125-134.

59. Woodcock, A. H. "Moisture Transfer in Textile Systems, Part I," Textile Research Journal, 32:8, August, 1962, 628-633.

60. Fanger, P. O. "Calculation of Thermal Comfort: Introduction of a Basic Comfort Equation," ASHRAE Transactions, V73, pt. 2, 1967, pp. III.4.1-III.4.20.

61. Sagarin, Edward (ed.). "Physiologic and Pharmocologic Aspects of Sweating," in Hermann, Franz, and Kanof, Norman B., Cosmetics Science and Technology. New York: Interscience, 1957.

62. Peters, John P. "Water Exchange," Physiological Review, 24:4, October, 1944, 491-509.

63. Fishbein, Morris (ed.). The New Illustrated Medical and Health Encyclopedia. Vol. 10, Perspiration, pp. 1455-1457. New York: H. S. Stuttman Co., Inc., 1964.

64. Kuno, Yas. Physiology of Human Perspiration. London: J. A. Churchill, Ltd., 1934.

65. Whelan, Margaret E., MacHattie, Lloyd E., Goodings, A. C., and Turl, L. H. "The Diffusion of Water Vapor Through Laminae with Particular Reference to Textile Fabrics," Textile Research Journal, 25:3, March, 1955, 197-223.

66. Rees, W. H. "The Protective Value of Clothing," Journal of the Textile Institute, 37:6, July, 1946, T132-153.

67. Kaswell, Ernest R. Textile Fibers, Yarns, and Fabrics. New York: Reinhold, 1953.

68. Frick, J. G., Kottes, Andrew B. W., Reid, David J., and Gautreaux, Gloria. "Durable-Press Knits of Cotton and Polyester," The Knitter, 37, April 19, 1974, 32-36.

69. Cotton Incorporated. "What Consumers Think about Today's Fibers and Fabrics." (n.d.)

70. Anon. "Cotton Steps into Pantyhose with New Dimensions in Next-to-the-Skin Comfort," American Fabrics, #100, Spring, 1974, 17.

71. Reichman, Charles. "Cotton in Knit Underwear: A Report," Knitting Outerwear Times, 38:20, May 12, 1969, 21-25.

72. Ludewig, Hermann. Polyester Fibres, Chemistry and Technology. New York: Wiley Interscience, 1964.

73. Morris, W. J. "Polyester Fibres," Textiles, 3:2, June, 1974, 30-35.

74. Werden, J. E., Fahnestock, M. K., and Galbraith, R. L. "Thermal Comfort of Clothing of Varying Fiber Content," Textile Research Journal, 29, 1957, 640-651.

75. Anon. "Are All Shirts Alike?" Consumers' Research Magazine, 57:6, June, 1964, 16-20.

76. Anon. "Men's Undershirts," Consumer Bulletin, 52:9, September, 1969, 17-20.

77. Anon. "Men's T Shirts," Consumer Reports, 36:1, January, 1971, 25-27.

78. Segall, William M. "What's Ahead for Cotton?" Canadian Textile Journal, 85, April 26, 1968, 51-53.

79. Hoffman, R. M., and Peterson, R. W. "Engineering of Fabrics from Blends with Synthetic Fibres," Journal of the Textile Institute, 49:8, August, 1958, 418-432.

80. Anon. "Cotton Blooms in Naturalspun," American Fabrics, #99, Winter, 1973, 24.

81. Anon. "Fabrics for All Seasons: Cotton-blend Knits Fill Comfort Criteria," Textile World, 124:8, August, 1974, 41.

82. Anon. "Cotton's Laboratory in Second Year," Knitting Times, 42:20, May 7, 1973, 33-36.

83. Reichman, Charles (ed.). Doubleknit Fabric Manual. New York: National Knitting Outerwear Association, 1961.

84. Gan, Ludwik R. "Knitter's Role in Producing Dimensionally Stable Knitted Wool Garments," Knitted Outerwear Times, 36:42, October 9, 1978, 18-25.

85. Penner, S. E., and Robertson, A. F. "Flow Through Fabric-like Structures," Textile Research Journal, 21:11, November, 1951, 775-788.

86. Clulow, Elaine E. "Permeability and Textiles," Textiles, 3:1, February, 1974, 19-23.

87. Latham, Barbara J. "The Structure of Shirting Fabrics in Relation to Comfort in Wear," Clothing Research Journal, 1:2, 1973, 3-27.

88. Grant, James, Andrews, N., Frederick, R., and Weiss, Louis C. "Physical Properties of Cotton Treated by Pad-Dry-Cure, Mild-Cure, Poly-Set, and Wet-Fix Processes," Textile Research Journal, 41:1, January, 1971, 44-51.

89. Moreau, Jerry P., Beninate, John V., Drake, George L., Jr., and Reeves, Wilson A. "Imparting Flame Retardancy to Cotton Knits," American Dyestuff Reporter, 61:1, January, 1972, 29-36.

90. Jones, Brian W. "Durable Press--What Price Cotton?" American Dyestuff Reporter, 60:1, January, 1971, 19-20.

91. Rees, W. H. "Physical Factors Determining the Comfort Performance of Textiles," Textiles for Comfort. Third Shirley International Seminar, Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, 1971.

92. Backer, Stanley. "The Relationship Between the Structural Geometry of a Textile Fabric and Its Physical Properties," Part IV: "Interstice Geometry and Air Permeability," Textile Research Journal, 21:10, October, 1951, 703-714.

93. Backer, Stanley. "The Relationship Between the Structural Geometry of a Textile Fabric and Its Physical Properties," Part IV: "Interstice Geometry and Air Permeability," Textile Research Journal, 18:11, November, 1948, 650-658.

94. Kanagy, Joseph R. "Adsorption of Water Vapor by Untanned Hide and Various Leathers at 100°F.," National Bureau of Standards Research Journal, 38, January, 1947, 119-128.

95. Fourt, Lyman. "Heat and Moisture Transfer Through Fabrics: Biophysics of Clothing." Washington: Harris Research Labs, Inc., AD 684 949, November, 1959. Microfilm NTIS, Springfield, Va. (Contract DA-19-129-QM 331).

96. Mecheels, J. "The Influence of Textile Structure on Its Permeability to Heat and Moisture." Orpington, England: Defence Research Information Centre, July, 1973. (N74-16253) (DRIC-Trans-3184) Microfilm from NTIS, Springfield, Va.

97. Best-Gordon, H. "Caring about Comfort," Textile Month, August, 1974, p. 72.

98. Bogaty, Herman, Hollies, Norman R. S., Hintermaier, John C., and Harris, Milton. "Some Properties of Serges Made from Blends of Wool with Acrylic Type Softeners," Textile Research Journal, 23:8, August, 1953, 536-544.

99. Watkins, Susan M. "New Careers for Home Economists: Designing Functional Clothing," Journal of Home Economics, 66:7, November, 1974, 33-38.

100. Gilling, D. R. "Assessment of the Comfort Properties of Military Clothing," Textiles for Comfort. Third Shirley International Seminar, Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, 1971.

101. Bruck, O. E. "The Design and Development of Hollow Filaments with a Brief Assessment of Their Potential Advantages," Textile Institute and Industry, May, 1965, pp. 118-121.

102. Anon. "The Next 100 Issues--Things to Come 1974-2001," American Fabrics, #100, Spring, 1974, 86.

103. Anon. "Surface Modifications of Hydrophobic Fibers," Sources and Resources, 1974/6, pp. 3-4.

104. Lewis, James. "Stain Repellent Finishes for Wool, Part 1," Wool Science Review, 48, March, 1974, 42-58.

105. Anon. Information Bulletin, "Zelcon TGF" Antigraying Agent, Dupont Industrial Chemicals. (n.d.)

106. Teijin Ltd. and Moriga, H. 1971. Fibrous Materials with Hydrophilic and Anti-static Properties and Improved Method for Producing the Same. USP 3,563,794.

107. Thackray, Wendy D., Imperial Chemical Industries, Ltd. "Polyethylene Terephthalate Fibers of Increased Moisture Absorption," USP 21458, Chemical Abstracts, 77:2, July 24-August 7, 1972, Abstr. 2144 f.

108. Pakshver, A. B. "Improve the Quality of Man-Made Fibres," Fibre Chemistry (translated from Russian original, #6, November-December, 1973; trans. pub. May, 1974; Vol. 5, #6 [no month], pp. 589-591; transl. from Khimicheskie Volokna, #6, November-December, 1973, 1-23).

109. Newns, A. C. "The Methods of Determining the Water Vapour Permeability of Laminae--A Review of the Literature," Journal of the Textile Institute Transactions, 41:8, August, 1950, T269-308.

110. Renbourn, E. T. "The Physiology of Clothing," Ciba Review, 1964/4.

111. Anon. The Lodz Textile Seminars--7. Testing and Quality Control, U.N. 1970. U.N. Industrial Development Organization: Vienna Training for Industrial Series No. 3.

112. Weiner, S. I. "Relationship of Moisture Vapor Transmission to the Structure of Textile Fabrics," Textile Chemists and Colorists, 2:22, November 4, 1970, 378-385.

113. Greenwood, K., Rees, W. H., and Lord, Joan. "Problems of Protection and Comfort in Modern Apparel Fabrics," Journal of the Textile Institute, 62:1, January, 1971, 56-59.

114. Turl, L. H., and Kennedy, J. E. "Method for the Measurement of the Resistance to Water Vapor Diffusion of Clothing Materials," in Wexler, Arnold (ed.), Humidity and Moisture, Vol. 4, Principles and Methods of Measuring Moisture in Liquids and Solids. New York: Reinhold Publishing Corp., 1965. Pp. 271-277.

115. Nice, G. R. "Apparatus for the Measurement of the Water-Vapour Permeability of Leather," Society of Leather Trades Chemists Journal, 35, 1951, 17-20.

116. Maeser, Mieth. "Comparison of Various Methods for Determining the Water Vapor Permeability of Vegetable-Retanned Side Leather," American Leather Chemists Association Journal, 53, 1958.

117. American Society for Testing and Materials. 1973 Annual Book of ASTM Standards, Part 15, Paper, Packaging, Cellulose, Casein, Flexible Barrier Materials, Business Copy Products; Leather Tests. ASTM D895-68, Standard Method of Test for Water Vapor Permeability of Packages, pp. 270-272.

118. American Society for Testing and Materials. 1973 Annual Book of ASTM Standards, Part 15, Paper, Packaging, Cellulose, Casein, Flexible Barrier Materials, Business Copy Products; Leather Tests. ASTM 96-66, Standard Method of Test for Water Vapor Transmission of Materials in Sheet Form, pp. 893-900.

119. Weiner, Louis I. "Moisture Vapor Transmission in Textile Fabrics," Textiles for Comfort. Third Shirley International Seminar, Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, Manchester, England, 1971.

120. Peirce, F. T., Rees, W. H., and Ogden, L. W. "Measurement of the Water Vapour Permeability of Textile Fabrics," Journal of the Textile Institute, 36:7, July, 1945, T169-176.

121. Rees, W. H. "Some Experiments on the Evaporation of Water from a Plane Surface," Journal of the Textile Institute, 36:7, July, 1945, T165-168.

122. Mark, Herman, McKetta, John J., Jr., and Othmer, Donald. Encyclopedia of Chemical Technology. 2nd ed. Vol. 20, "Textile Testing," pp. 33-62. New York: Interscience, 1969.

123. Hock, Charles W., Sookne, Arnold M., and Harris, Milton. "Thermal Properties of Moist Fabrics," Journal of Research, National Bureau of Standards, 32, May, 1944, 229-252.

124. Cohen, Gabrielle G., and Baker, Cameron A. "Measuring Combined Effects of Moisture Transmission and Thermal Conductivity," American Dyestuff Reporter, 58:21, October 20, 1969, 32-36.

125. Harper, Robert J., Jr. Research Leader--Pilot Plant Processes Research--Cotton Textile Chemistry Laboratory. USDA--Agricultural Research Services--Southern Regional Research Center, New Orleans, Louisiana, September 19, 1974.

126. Martin, H. De V., and Goldman, R. F. "Comparison of Physical, Biophysical and Physiological Methods of Evaluating the Thermal Stress Associated with Wearing Protective Clothing," Ergonomics, 15:3, March, 1972, 337-342.

127. Anon. Institute for Environmental Research. Manhattan: Kansas State University (n.d.).

128. Andreen, J. H., Gibson, J. W., and Wetmore, O. C. "Fabric Evaluations Based on Physiological Measurement of Comfort," Textile Research Journal, 23:1, January, 1953, 11-22.

129. Gilling, D. R., Streets, D. F., and Dickins, T. L. "Breathable Waterproof Fabrics: Physical Tests and Physiological Trials." Army Personnel Research Establishment, Report 6/70, Farnsborough, England.

130. McIntyre, D. A., and Griffiths, I. D. "Subjective Response to Radiant and Convective Environments," Environmental Research, 5:4, December, 1972, 471-487.

131. Haisman, M. F., and Goldman, R. F. "Physiological Evaluations of Armoured Vests in Hot-Wet and Hot-Dry Climates," Ergonomics, 17:1, January, 1974, 1-12.

132. Henschel, Austin, and Hanson, H. E. "Heat Stress in the Desert," Mechanical Engineering, 82:6, June, 1960, 59-62.

133. Britt, Kenneth (ed.). Handbook of Pulp and Paper Technology. 2nd ed. Chapter 9-2, Paper Testing, pp. 665-682. New York: Van Nostrand Reinhold Co., 1970.

134. Dyba, Raymond V., and Miller, Bernard. "Dynamic Measurements of the Wetting of Single Filaments," Textile Research Journal, 40:10, October, 1970, 884-890.

135. Dyba, Raymond, and Miller, Bernard. "Evaluation of Wettability from Capillary Rise Between Filaments," Textile Research Journal, 39:10, October, 1969, 962-970.

136. Lichstein, B. M. "Demand Wettability--A New Method for Measuring Absorbency Characteristics of Fabrics," Sources and Resources, 1974/3, pp. 30-32.

137. American Association of Textile Chemists and Colorists. 1973 Technical Manual of the American Association of Textile Chemists and Colorists, Vol. 49. Research Triangle Park, N.C.: American Association of Textile Chemists and Colorists, 1973.

138. American Society for Testing and Materials. 1970 Annual Book of ASTM Standards, Part 25, Textile Materials--Fibers and Zippers; High Modulus Fibers. Philadelphia: ASTM, 1970.

139. Arons, Gilbert N., Macnair, Richard N., and Erickson, Richard L. "Sorption Characteristics of Activated Carbon Fabrics," Textile Research Journal, 43:9, September, 1973, 539-543.

140. Dixon, W. J. (ed.). BMD Biomedical Computer Programs, University of California Publication in Automatic Computation No. 2. Los Angeles: University of California Press, 1968.

141. Winer, B. J. Statistical Principles in Experimental Design. 2nd ed. New York: McGraw-Hill Book Co., 1971.

142. Anon. "A Selection of S.I. Units Recommended for Use in the Textile Industry," Textile Institute and Industry, 11:7, July, 1973, 189.

143. Rees, W. H. "The Protective Value of Clothing," Journal of the Textile Institute, 37, 1946, 132-153.

144. Anon. Scott Acquell Foam. Chester, Pa.: Scott Paper Co. (n.d.).

145. Weireck, E. S. "Textile Testing Laboratory," American Dyestuff Reporter, 21, 1932, 154.

146. Padgett, Rose. Textile Chemistry and Testing in the Laboratory. 3rd ed. Minneapolis: Burgess Publishing Co., 1962.

BIBLIOGRAPHY

Single Volume Works

Adamson, Arthur W. A Textbook of Physical Chemistry. New York: Academic Press, 1973.

Adolph, E. F., and Associates. Physiology of Man in the Desert. New York: Interscience, 1947.

Alexander, Allen L. (Symposium Chairman). Interaction of Liquids at Solid Substrates. Adv. in Chem. Series #87. Washington: American Chemical Society, 1968.

Alexander, Peter, and Hudson, Robert F. Wool: Its Chemistry and Physics. New York: Reinhold Publishing Corp., 1954.

Alexander, Peter, and Hudson, Robert F. Wool: Its Chemistry and Physics. 2nd ed. New Jersey: Franklin Publishing Co., Inc., 1963.

Alford, M. W., Jarvis, R. N., and Griffiths, P. M. "The Geometry of Warp-Knitted Structures," in Studies in Modern Fabrics, Papers of the Diamond Jubilee Conference of the Textile Institute, 1970. Manchester, England: Textile Institute and Contributors, 1970.

American Society for Safety Engineers. A Selected Bibliography of Reference Materials in Safety Engineering. Chicago: ASSE, 1967.

Angus, T. C. The Control of Indoor Climate. New York: Pergamon Press, 1968.

Auliciens, Andris. The Atmospheric Environment: A Study of Comfort and Performance. Toronto: University of Toronto, 1972.

Barry, R. G., and Chorley, R. J. Atmosphere, Weather, and Climate. London: Methuen and Co., Ltd., 1971.

Beevers, R. B. Experiments in Fibre Physics. London: Butterworths, 1970.

Bennett, C. O., and Myers, J. E. *Momentum, Heat, and Mass Transfer*. New York: McGraw-Hill Book Co., 1962.

Brinckerhoff, Richard F., Cross, Judson B., and Lazarus, Arthur. *Exploring Physics*. 2nd ed. New York: Harcourt, Brace and World, Inc., 1959.

Britt, Kenneth (ed.). "Paper Testing," *Handbook of Pulp and Paper Technology*. 2nd ed. New York: Van Nostrand Reinhold Co., 1970. Pp. 665-682.

Brobeck, John R. (ed.). *Best and Taylor's Physiological Basis of Medical Practice*. 9th ed. Baltimore: Williams and Wilkins Co., 1973.

Brown, Clinton C. *Methods in Psychophysiology*. Baltimore: Williams and Wilkins Co., 1967.

Brown, Peter. *Knitting Principles*. Burlington, N.C.: Burlington Printing Services Co., 1972.

Burton, Alan C., and Edholm, Otto G. *Man in a Cold Environment: Physiological and Pathological Effects of Exposure to Low Temperatures*. London: Edward Arnold Publishers, Ltd., 1955.

Carroll-Porczynski, C. Z. *Natural Polymers; Man-Made Fibres*. New York: Academic Press, Inc., 1961.

Chapanis, Alphonse. *Research Techniques in Human Engineering*. Baltimore: Johns Hopkins Press, 1959.

Chapman, Brian N., and Anderson, J. C. (eds.). *Science and Technology of Surface Coating*. London: Academic Press, 1974.

Clark, John W., Viessman, Warren, and Hammer, Mark J. *Water Supply and Pollution Control*. 2nd ed. Scranton: International Text Book Co., 1971.

Clarke, Loyal, and Davidson, Robert L. *Manual for Process Engineering Calculations*. 2nd ed. New York: McGraw-Hill Book Co., 1962.

Cochran, William G., and Cox, Gertrude M. *Experimental Designs*. 2nd ed. New York: John Wiley and Sons, Inc., 1957.

Csanady, G. T. *Turbulent Diffusion in the Environment*. Boston: D. Reidel Publishing Co., 1973.

Daniell, Alfred. *Physics for Students of Medicine Book*. 2nd ed. London: MacMillan and Co., Ltd., 1909.

Danielli, J. F., and Pankhurst, K. G. A. (eds.). Surface Phenomena in Chemistry and Biology. New York: Pergamon Press, 1958.

Davies, J. T., and Rideal, E. K. Interfacial Phenomena. New York: Academic Press, 1961.

Dill, D. B., Adolph, E. F., and Wilber, C. G. (eds.). Handbook of Physiology. Washington: American Physiological Society, 1964.

Dittmer, Howard J. Modern Plant Biology. New York: Van Nostrand Reinhold Co., 1972.

Douglas, H. K. Lee, and Minard, David (eds.). Physiology, Environment, and Man. New York: Academic Press, 1970.

Edholm, O. G. The Biology of Work. New York: World University Library, 1967.

Edholm, O. G., and Bacharach, A. L. The Physiology of Human Survival. New York: Academic Press, 1965.

Fanger, P. O. Thermal Comfort: Analysis and Applications in Environmental Engineering. Copenhagen: Danish Technical Press, 1970.

Fisher, Frank (ed.). Man Living in the Arctic. Natick, Mass.: Quartermaster Research and Engineering Center, 1961.

Flugel, J. C. The Psychology of Clothes. New York: International University Press, 1930.

Fourt, Lyman, and Hollies, Norman R. S. Clothing Comfort and Function. New York: Marcel Dekker, Inc., 1970.

Fowkes, Fredrick M. (ed.). Hydrophobic Surfaces. New York: Academic Press, 1969.

Garrett, H. E. Surface Active Chemicals. New York: Pergamon Press, 1972.

Garver, Walter. Textile Laboratory Manual. 2nd ed. New York: Textile Book Service, 1951.

Gilbrech, Donald A. Fluid Mechanics. 2nd printing. Belmont, Ca.: Wadsworth Publishing Co., Inc., 1965.

Goates, J. Rex., and Ott, J. Bevan. Chemical Thermodynamics: An Introduction. New York: Harcourt, Brace, Jovanovich, Inc., 1971.

Gomer, Robert, and Smith, Cyril Stanley (eds.). Structure and Properties of Solid Surfaces. Chicago: University of Chicago Press, 1953.

Green, Herbert S. The Molecular Theory of Fluids. New York: Dover Publishers, Inc., 1969.

Grover, Elliot B., and Hamby, D. S. Handbook of Textile Testing and Quality Control. New York: Interscience, 1960.

Hall, David M. Chemical Testing of Textiles--Laboratory Manual. Auburn, Ala.: Department of Textile Engineering, 1974.

Hardy, James D., Gagge, A. Pharo, and Stolwijk, Jan A. J. Physiological and Behavioral Temperature Regulation. Springfield, Ill.: Charles C. Thomas, 1970.

Harper, Robert J., Jr. Durable Press Cotton Goods. Walford, England: Merrow, 1971.

Harries, Nancy Garrison, and Harries, Thomas Edward. Textiles: Decision Making for the Consumer. New York: McGraw-Hill Book Co., 1974.

Harris, Norman C. Modern Air Conditioning Practice. New York: McGraw-Hill Book Co., 1959.

Hathorne, Berkeley L. Woven Stretch and Textured Fabrics. New York: Interscience, 1964.

Haven, George B. Mechanical Fabrics: A Treatise upon Their Manufacture, Construction, Testing and Specification. New York: John Wiley and Sons, Inc., 1932.

Hearle, J. W. S., and Peters, R. H. Fibre Structure. Manchester, England: The Textile Institute, 1963.

Hearle, J. W. S., and Peters, R. H. Moisture in Textiles. New York: Textile Book Publishers, Inc., 1960.

Henke, Russell W. Introduction to Fluid Mechanics. 2nd printing. Reading, Mass.: Addison-Wesley Publishing Co., 1967.

Hermans, P. H. Contribution to the Physics of Cellulose Fibers. New York: Elsevier Publishing Co., Inc., 1946.

Herrmann, Franz, and Kanof, Norman B. "Physiologic and Pharmacologic Aspects of Sweating," in Edward Segarin (ed.), Cosmetics Science and Technology. New York: Interscience, 1957.

Hopkins, Giles E. Wool as an Apparel Fiber. New York: Rinehart and Co., 1953.

Horn, Marilyn J. The Second Skin. Boston: Houghton Mifflin Co., 1968.

Humphreys, W. F. The Physics of Air. New York: McGraw-Hill Book Co., 1929.

Irvine, Thomas F., Jr., and Hartnett, James P. Advances in Heat Transfer. New York: Academic Press, 1973.

Itoh, Shinji, Ogata, Korehico, and Yoshimura, Hisato. Advances in Climatic Physiology. Tokyo: Igaku Shoin, Ltd., 1972.

Jellinek, H. H. G. (ed.). Water Structure at the Water-Polymer Interface. New York: Plenum Press, 1972.

John, Peter W. M. Statistical Design and Analysis of Experiments. New York: The Macmillan Co., 1971.

Johnson, Keith. Antistatic Agents. Park Ridge, N.J.: Noyes Data Corp., 1972.

Joseph, Marjory L. Textile Science. 2nd ed. New York: Holt, Rinehart and Winston, Inc., 1972.

Kaswell, Ernest R. Textile Fibers, Yarns, and Fabrics: A Comprehensive Survey of Their Behavior with Specific Reference to Wool. New York: Reinhold, 1953.

Keele, Cyril A., and Neil, Eric. Samson Wright's Applied Physiology. 12th ed., revised. London: Oxford University Press, 1971.

Kendrew, W. G. Climatology. 2nd ed. Oxford: At the Clarendon Press, 1957.

Kuno, Yas. Physiology of Human Perspiration. London: J. and A. Churchill, Ltd., 1934.

Lamb, Sir Horace. Hydrodynamics. 6th ed. New York: Dover Public, 1932.

Laube, Herbert L. How to Have Air-Conditioning and Still Be Comfortable. Birmingham, Mich.: Business News Publishing Co., 1971.

Lester, T. Earls. A Brief Course in Physics for Students of Home Economics. New York: Prentice-Hall, Inc.,

Linsley, Ray K., and Franzini, Joseph B. Water-Resources Engineering. 2nd ed. New York: McGraw-Hill Book Co., 1972.

Ludewig, Hermann. Polyester Fibres Chemistry and Technology. New York: Wiley-Interscience, 1964.

Mallan, Lloyd. Suiting up for Space--The Evolution of the Space Suit. New York: The John Day Co., 1971.

Marchessault, R. H., and Skaar, Christen (ed.). Surfaces and Coatings Related to Paper and Wood. Syracuse: Syracuse University Press, 1967.

Mark, H., Wooding, Norman S., and Atlas, Sheldon M. Chemical Aftertreatment of Textiles. New York: Wiley-Interscience, 1971.

Marsh, J. T. An Introduction to Textile-Finishing. 2nd ed. London: Chapman and Hall, Ltd., 1966.

Mauersberger, Herbert R. Matthews' Textile Fibers: Their Physical, Microscopic, and Chemical Properties. 6th ed. New York: John Wiley and Sons, 1954.

McFarlane, Samuel B. Technology of Synthetic Fibres. New York: Fairchild, 1953.

Meredith, R., and Hearle, J. W. S. Physical Methods of Investigating Textiles. New York: Textile Book Publishers, Inc., 1959.

Moilliet, J. L. Waterproofing and Water Repellency. New York: Elesevier Publishing Co., 1963.

Morton, W. E., and Hearle, J. W. S. Physical Properties of Textile Fibres. Manchester, England: The Textile Institute, 1962.

Munn, R. E. Biometeorological Methods. New York: Academic Press, 1970.

Munro, Lloyd A. Chemistry in Engineering. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964.

Newburgh, L. H. (ed.). Physiology of Heat Regulation. Philadelphia: W. B. Saunders Co., 1949.

Olivieri, Joseph B. How to Design Heating-Cooling Comfort Systems. Rev. ed. Birmingham, Mich.: Business News Publishing Co., 1971.

Padgett, Rose. Textile Chemistry and Testing in the Laboratory. 3rd ed. Minneapolis: Burgess Publishing Co., 1962.

Paling, D. F. Ward Knitting Technology. 2nd ed. Metuchen, N.J.: Textile Book Service, 1965.

Press, J. J. (ed.). Man-Made Textile Encyclopedia. New York: Textile Book Publishers, Inc., 1959.

Raber, B. F., and Hutchinson, F. W. Refrigeration and Air Conditioning Engineering. New York: John Wiley and Sons, Inc., 1945.

Reid, Robert C., and Sherwood, Thomas K. The Properties of Gases and Liquids--Their Estimation and Correlation. New York: McGraw-Hill Book Co., 1958.

Renbourn, E. T. Physiology and Hygiene of Materials and Clothing. Watford Herts, England: Merrow Publishing Co., Ltd., 1971.

Rideal, Eric Keightley. An Introduction to Surface Chemistry. Cambridge: At the University Press, 1926.

Riehl, Herbert. Introduction to the Atmosphere. 2nd ed. New York: McGraw-Hill Book Co., 1972.

Rohsenow, Warren M., and Hartnett, James P. Handbook of Heat Transfer. New York: McGraw-Hill Book Co., 1973.

Rothman, Stephen. Physiology and Biochemistry of the Skin. Chicago: University of Chicago Press, 1954.

Sissom, Leighton E., and Pitts, Donald. Elements of Transport Phenomena. New York: McGraw-Hill Book Co., 1972.

Sittig, Marshak. Polyester Fiber Manufacture. Park Ridge: Noyes Data Corp., 1971.

Skaar, Christen, and Marchessault, R. H. (eds.). Surfaces and Coatings Related to Paper and Wood. Syracuse: Syracuse University Press, 1967.

Skelland, A. H. P. Non-Newtonian Flow and Heat Transfer. New York: John Wiley and Sons, Inc., 1967.

Skinkle, John H. Textile Testing: Physical, Chemical, and Microscopical. Brooklyn: Chemical Publishing Co., 1949.

Speel, H. C., and Schwartz, E. W. K. Textile Chemicals and Their Auxiliaries. New York: Reinhold, 1957.

Tate, Merle W., and Clelland, Richard C. Nonparametric and Shortcut Statistics. Danville, Ill.: Interstate Printers and Publishers, Inc., 1957.

Taylor, Marjorie A. Technology of Textile Properties: An Introduction. London: Forbes Publishers, Ltd., 1972.

Textile Institute. Studies in Modern Fabrics. Papers of the Diamond Jubilee Conference of the Textile Institute, 1970. Manchester, England: The Textile Institute and Contributors, 1970.

Tokay, Elbert. Fundamentals of Physiology. Rev. ed. New York: Barnes and Noble, Inc., 1967.

Trotman, E. R. Dyeing and Chemical Technology of Textile Fibres. 4th ed. London: Griffin, 1970.

Tuffnell, Robert, and Luke, Dudley. The Nature of Physical Chemistry. New York: Elsevier Publishing Co., Inc., 1969.

Walters, C. Glenn, and Paul, Gordon W. Consumer Behavior: An Integrated Framework. Homewood, Ill.: Richard D. Irwin, Inc., 1970.

Weiner, Louis I. Textile Fabric Design Tables. Stamford, Conn.: Technomic Publishing Co., Inc., n.d.

Wentworth, Wayne E., and Ladner, S. Jules. Fundamentals of Physical Chemistry. Belmont, Ca.: Wadsworth Publishing Co., 1972.

West Point Pepperell, Staff (ed.). Physical Testing at West Point Pepperell. Atlanta, Ga.: W. R. C. Smith Publishing Co., 1967-68.

Willows, R. S., and Hatschek, E. Surface Tension and Surface Energy and Their Influence on Chemical Phenomena. 3rd ed. Philadelphia: P. Blakiston's Son and Co., 1923.

Winer, B. J. Statistical Principles in Experimental Design. 2nd ed. New York: McGraw-Hill Book Co., 1962.

Winslow, C. E. A., and Herrington, L. P. Temperature and Human Life. Princeton, N.J.: Princeton University Press, 1949.

Woessner, Huijing F., Jr. (ed.). The Molecular Basis of Biological Transport. New York: Academic Press, 1972.

Woods, H. J. Physics of Fibres. London: Institute of Physics, 1955.

Yousef, Mohamed K., Horvath, Steven M., and Bullard, Robert W. Physiological Adaptations. New York: Academic Press, 1972.

Multivolume Works and Series

American Association of Textile Chemists and Colorists. 1973 Technical Manual of the AATCC. Research Triangle Park, N.C.: AATCC, 1973.

American Society of Heat, Refrigerating and Air-Conditioning Engineers, Inc. Guide and Data Book: Fundamentals and Equipment for 1965 and 1966. New York: ASHRAE, 1965.

American Society for Testing Materials. 1973 Annual Book of ASTM Standards. Part 15: Paper; Packaging, Cellulose; Casein; Flexible Barrier Materials; Business Copy Products; Leather. Philadelphia: ASTM, 1973.

American Society for Testing Materials. 1973 Annual Book of ASTM Standards. Part 24: Textile Materials--Yarns, Fabrics, and General Methods. Philadelphia: ASTM, 1973.

American Society for Testing Materials. 1973 Annual Book of ASTM Standards. Part 25: Textile Materials--Fibers, Zippers, High Modulus Fibers. Philadelphia: ASTM, 1973.

American Society for Testing Materials. Symposium on Properties of Surfaces, Los Angeles, 1962. ASTM Materials Science Series No. 4. Philadelphia: ASTM, 1963.

Anon. The Lodz Textile Seminars: 7. Testing and Quality Control. Training for Industrial Series No. 3. Vienna: U.N. Industrial Development Organization, 1970.

Anon. Materials Control for Double Jersey Fabric. Book 1, Yarn Purchasing and Storage. Hosiery and Knitwear EDC, National Economic Development Office. London: Her Majesty's Stationery Office, 1970.

Anon. Materials Control for Double Jersey Fabric. Book 2, The Testing of Yarn. Hosiery and Knitwear EDC, National Economic Development Office. London: Her Majesty's Stationery Office, 1970.

Anon. Materials Control for Double Jersey Fabric. Book 3, Yarn Issue and Control of Yarn Losses. Hosiery and Knitwear EDC, National Economic Development Office. London: Her Majesty's Stationery Office, 1970.

Anon. Materials Control for Double Jersey Fabric. Book 4, Control of Fabric Quality. Hosiery and Knitwear EDC, National Economic Development Office. London: Her Majesty's Stationery Office, 1970.

Asimov, Isaac. Understanding Physics. Vol. I, Motion, Sound, Heat. New York: Walker and Co., 1966.

Behmann, F. W. "Influence of Clothing Material on the Performance in Relation to Common Physiological Factors," in Vol. 3, Pt. 4, Proceedings of the International Wool Textile Research Conference, 1965. Paris: Institute Textile de France, 1965.

Benning, Calvin J. Plastic Foams: The Physics and Chemistry of Product Performance and Process Technology. Vol. VII, Structure, Properties and Applications. New York: Wiley-Interscience, 1969.

Blockley, W. V., and Craig, L. Taylor. "Human Tolerance Limits for Extreme Heat," ASHVE Transactions, Vol. 55. New York: American Society of Heating and Ventilating Engineers, 1949. Pp. 399-412.

Brown, J. H. U., and Gann, Donald S. Engineering Principles in Physiology. Vol. VII. New York: Academic Press, 1973.

Brunauer, Stephen. The Adsorption of Gases and Vapors. Vol. I, Physical Adsorption. Princeton: Princeton University Press, 1945.

Cole, Arthur (ed.). Theoretical and Experimental Biophysics. Vol. I. New York: Marcel Dekker, Inc., 1967.

Dixon, W. J. (ed.). BMD Biomedical Computer Programs. University of California Publication in Automatic Computation, No. 2. Los Angeles: University of California Press, 1968.

Dixon, W. J. (ed.). Biomedical Computer Programs. X-Series Supplement, University of California Publication in Automatic Computation, No. 3. Los Angeles: University of California Press, 1969.

Ede, A. J. An Introduction to Heat Transfer Principles and Calculations. International Series of Monographs in Heating, Ventilation and Refrigeration. Vol. 2. New York: Pergamon Press, 1967.

Fanger, P. O. "Calculation of Thermal Comfort: Introduction of a Basic Comfort Equation," ASHRAE Transactions, Vol. 73, Pt. 2. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1967. Pp. III.4.1-III.4.20.

Fishbein, Morris (ed.). "Perspiration," The New Illustrated Medical and Health Encyclopedia. Vol. 10. New York: H. S. Stuttman Co., Inc., 1964. Pp. 1455-1457.

Gagge, A. P., Stolwijk, J. A. J., and Nishi, Y. "An Effective Temperature Scale Based on a Simple Model of Human Physiological Regulatory Response," ASHRAE Transactions, Vol. 77, Pt. 1. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1971.

Gilling, D. R. "Assessment of the Comfort Properties of Military Clothing," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Goldman, Ralph F. "Clothing Design for Comfort and Work Performance in Extreme Thermal Environments," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Gonzalez, Richard R., and Gagge, A. Pharo. "Magnitude Estimates of Thermal Discomfort During Transients of Humidity and Operative Temperature and Their Relation to the New ASHRAE Effective Temperature," ASHRAE Transactions, Vol. 79, Pt. 1. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1973.

Gould, Robert F. Contact Angle, Wettability, and Adhesion. Advances in Chemistry Series, 43. Washington: American Chemical Society, 1964.

Greenwood, K. "The Language of Comfort," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Greenwood, K., Rees, W. H., and Lord, Joan. "Problems of Protection and Comfort for Modern Apparel Fabrics," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Hamby, Dame Scott (ed.). The American Cotton Handbook. 3rd ed. Vol. I. New York: Interscience, 1965.

Hamby, Dame Scott (ed.). The American Cotton Handbook. 3rd ed. Vol. II. New York: Interscience, 1961.

Hearle, J. W. S., Grosberg, P., and Backer, S. Structural Mechanics of Fibers, Yarns, and Fabrics. Vol. I. New York: Wiley-Interscience, 1969.

Hole, L. G., and Keech, B. "The Comfort Properties of Footwear Materials," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, 1971.

Hollies, Norman R. S. "The Comfort Characteristics of Next-to-Skin Garments, Including Shirts," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, 1971.

Jones, David M. "A Critical Review of New Developments in Textiles," New Fibers and Textiles. Second Shirley International Seminar, September 29-October 1, 1970. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Joy, F. A., and Queer, E. R. "Permeance Measurement Improved by Special Cell," ASH&VE Transactions, Vol. 55, No. 1371. New York: American Society of Heating and Ventilating Engineers, 1949. Pp. 377-412.

Kemp, Sheila. "The Consumer's Requirements for Comfort," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Kerslake, D. McK. "Physiological Aspects of Comfort," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, 1971.

Konz, S., and Aurora, D. "An Evaluation of a Dynamic Cooling Shirt," ASHRAE Transactions, No. 2262, Pt. 1. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1973. Pp. 52-61.

Kumins, Charles A. (ed.). Transport Phenomena Through Polymer Films. Journal of Polymer Science: Polymer Symposia No. 41. New York: Interscience, 1973.

Mark, H. F., Atlas, S. M., and Cernia, E. Man-Made Fibers--Science and Technology. Vol. 3. New York: Interscience, 1968.

Mark, Herman, McKetta, John J., Jr., and Othmer, Donald. "Textile Testing," Encyclopedia of Chemical Technology. 2nd ed. Vol. 20. New York: Interscience, 1969. Pp. 33-62.

Mark, Herman, Gaylord, Norman, and Bikales, Norbert M. (eds.). "Hollow-Fiber Membranes," Encyclopedia of Polymer Science and Technology. Vol. 15. New York: Interscience, 1971.

Matijevic, Egon. Surface and Colloid Science. Vol. 2. New York: Wiley-Interscience, 1969.

McNall, P. E., Jr., Jaax, J., Rohles, F. H., Nevins, R. G., and Springer, W. "Thermal Comfort (Thermally Neutral) Conditions for Three Levels of Activity," ASHRAE Transactions, Vol. 73, Pt. 1. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1967. Pp. I.3.1-I.3.14.

Mecheels, J. "Concomitant Heat and Moisture Transmission Properties of Clothing," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, 1971.

Nishi, Y., and Gagge, A. P. "Moisture Permeation of Clothing--A Factor Governing Thermal Equilibrium and Comfort," ASHRAE Transactions, Vol. 76, Pt. 1. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1970. Pp. 137-145.

Olesen, Soren, Bassing, J., and Panger, P. O. "Physiological Comfort Conditions at Sixteen Combinations of Activity, Clothing, Air Velocity and Ambient Temperature," ASHRAE Transactions, Vol. 78, Pt. 2. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1972. Pp. 199-206.

Ott, Emil, Spurlin, Harold, and Grafflin, Mildred W. Cellulose and Cellulose Derivatives. Part I. New York: Interscience, 1954.

Peters, R. H. Textile Chemistry. Vol. I, The Chemistry of Fibres. New York: Elsevier Publishing Co., 1963.

Peters, R. H. Textile Chemistry. Vol. II, Impurities in Fibres; Purification of Fibres. New York: Elsevier Publishing Co., 1967.

Rapp, George M. "Convective Heat Transfer and Convective Coefficients of Nude Man, Cylinders and Spheres at Low Air Velocities," ASHRAE Transactions, Vol. 79, Pt. 1. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1973. Pp. 75-96.

Rebenfeld, Ludwig (ed.). Proceedings of the Fourth International Wool Textile Research Conference, Parts I and II. New York: Interscience, 1971.

Rees, W. H. "Physical Factors Determining the Comfort Performance of Textiles," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, 1971.

Reichman, Charles (ed.). Advanced Knitting Principles. New York: National Knitted Outerwear Association, 1964.

Reichman, Charles (ed.). Double Knit Fabric Manual. New York: National Knitted Outerwear Association, 1961.

Reichman, Charles (ed.). Knitting Dictionary. New York: National Knitted Outerwear Association, 1974.

Reichman, Charles (ed.). Knitting Encyclopedia. New York: National Knitted Outerwear Association, 1972.

Reichman, Charles (ed.). Knitting Times Yearbook, 1974. New York: Knitted Outerwear Association, 1974.

Reichman, Charles, Lancashire, J. B., and Darlington, K. D. Knitted Fabric Primer. New York: National Knitted Outerwear Association, 1967.

Renbourn, E. T. "The Psychology of Clothing with Materials in Mind," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, 1971.

Rohles, R. H., Jr. "The Modal Comfort Envelope a New Approach toward Defining the Thermal Environment in Which Sedentary Man is Comfortable," ASHRAE Transactions, Vol. 76, Pt. 2. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1970. Pp. 308-314.

Rohles, Frederick H., Jr. "The Revised Modal Comfort Enveloped," ASHRAE Transactions, Vol. 79, Pt. 2. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1973. Pp. 52-59.

Rohles, R. H., and Nevins, R. G. "The Nature of Thermal Comfort for Sedentary Man," ASHRAE Transactions, Vol. 77, Pt. 1. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1971. Pp. 239-246.

Rohles, Frederick H., Jr., Woods, James E., and Nevins, Ralph G. "The Effects of Air Movement and Temperature on Thermal Sensations of Sedentary Man," ASHRAE Transactions, Vol. 80, Pt. 1. Proceedings of Semiannual Meeting, Los Angeles, 1974. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1974. P. 101.

Rohles, Frederick H., Jr., Woods, James E., and Nevins, Ralph G. "The Influence of Clothing and Temperature on Sedentary Comfort," ASHRAE Transactions, Vol. 79, Pt. 2. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1973. Pp. 71-80.

Spencer-Smith, J. L. "Some Aspects of Tropical Clothing," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Sprague, C. H., and McNall, P. E., Jr. "The Effects of Fluctuating Temperature and Relative Humidity on the Thermal Sensation (Thermal Comfort) of Sedentary Subjects," ASHRAE Transactions, Vol. 76, Pt. 1.

New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1970. Pp. 146-156.

Sprague, Clyde H., Jai, R. B., Nevins, Ralph G., and Azer, N. Z. "The Prediction of Thermal Sensation for Man in Moderate Thermal Environments via a Simple Thermoregulatory Model," ASHRAE Transactions. Proceedings of Semiannual Meeting, Los Angeles, 1974. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1974. Pp. 130-146.

Sprague, Clyde H., and Munson, Deanna M. "A Composite Ensemble Method for Estimating Thermal Indulating Values of Clothing," ASHRAE Transactions, No. 2299. Proceedings of Semiannual Meeting, Los Angeles, 1974. New York: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1974.

Sweeting, Orville J. (ed.). The Science and Technology of Polymer Films. Vol. I. New York: Wiley-Interscience, 1968.

Sweeting, Orville J. The Science and Technology of Polymer Films. Vol. VII. New York: Wiley-Interscience, 1971.

Thewlis, J. (ed.). "Adsorption," Encyclopedic Dictionary of Physics. Vol. I. New York: Pergamon Press, 1962. Pp. 27-29.

Tromp, S. W. (ed.). Biometeorology. Proceedings of the Second International Bioclimatological Congress. Pergamon Press book. New York: The Macmillan Co., 1962.

Tromp, S. W., and Bouma, Janneke J. Biometeorology, Vol. 5, Pt. I. Supplement to Vol. 16 (1972) of International Journal of Biometeorology. Amsterdam: Swets and Zeitlinger, 1972.

Tromp, S. W., and Weihe, W. H. Biometeorology, Vol. 2, Pt. 1. Amsterdam: Swets and Zeitlinger, 1967.

Tromp, S. W., and Weihe, W. H. Biometeorology, Vol. 3. Amsterdam: Swets and Zeitlinger, 1967.

Tromp, S. W., and Weihe, W. H. Biometeorology, Vol. 4, Pt. 1. Amsterdam: Swets and Zeitlinger, 1970.

Tromp, S. W., Weihe, W. H., and Bouma, Janneke J. Biometeorology, Vol. 5, Pt. 2. Amsterdam: Swets and Zeitlinger, 1972.

Turl, L. H., and Kennedy, J. E. "Method for the Measurement of the Resistance to Water Diffusion of Clothing Materials." In Wexler, Arnold (ed.), Humidity and Moisture. Vol. 4, Principles and Methods of Measuring Moisture in Liquids and Solids. New York: Reinhold Publishing Corp., 1965.

Vines, A. E., and Rees, N. Plant and Animal Biology. 3rd ed. Vol. II. London: Sir Isaac Pitman and Sons, Inc., 1968.

Von Bergen, Werner (ed.). Wool Handbook. 3rd ed. Vol. I. New York: Interscience, 1963.

Von Bergen, Werner (ed.). Wool Handbook. Vol. II, Pts. I and II. New York: Interscience, 1963.

Weber, Walter J., Jr., and Matijevic, Egon. Adsorption from Aqueous Solution. Advance in Chemistry Series No. 79. Washington: American Chemical Society, 1968.

Weiner, Louis I. "Moisture Vapor Transmission in Textile Fabrics," Textiles for Comfort. Third Shirley International Seminar. Manchester, England: Cotton, Silk, and Man-Made Fibers Research Association, Shirley Institute, 1971.

Wexler, Arnold, and Wildhack, William A. (eds.). Humidity and Moisture Measurement and Control in Science and Industry. Vol. 3, Fundamentals and Standards. New York: Reinhold, 1965.

Whittow, G. Causey. Comparative Physiology of Thermoregulation. Vol. II, Mammals. New York: Academic Press, 1971.

Government Documents

Brandt, Harold H., and Riddell, Albert. Spacer Fabric Development. Textile Engineering Lab Report No. 183. Natick, Mass.: Quartermaster Research and Development Center, April 1967.

Canadian Government Specifications Board. Extract from CGSB Standard 4-GP-2, Canadian Standard Textile Test Method. Method 49-1962, Resistance of Materials to Water Vapor Diffusion.

Clayton, L. Yvonne. *Mothers' Attitudes toward Cotton and Other Fibers in Children's Lightweight Clothing*. Marketing Research Report No. 1026. Econ. Res. Serv. USDA.

Clayton, L. Yvonne, and Sherman, Lorna R. *Homemakers' Opinions about Fibers in Selected Household Items: A Nationwide Survey*. USDA Statistical Reporting Service. Marketing Research Report No. 958, June, 1972.

Ellison, A. H., and Zisman, W. A. *Wettability of Nylon, Polyethylene Tirephthalate, and Polystyrene by Hydrogen-Bonding and Halogenated Liquids*. NRL Report 4362. PB 111448. Washington: Naval Research Laboratory, U.S. Department of Commerce, Office of Technical Services.

Fourt, Lyman. *Heat and Moisture Transfer Through Fabrics: Biophysics of Clothing*. Contract DA-19-129-QM-331. Washington: Harris Research Labs, Inc., November, 1959.

Gilling, D. R., Streets, D. F., and Dickins, T. L. *Breathable Waterproof Fabrics: Physical Tests and Physiological Trials*. Report 6/70. Farnsborough, England: Army Personnel Research Establishment, 1970.

Handbook of Human Engineering Data for Design Engineers. Tech. Rep.-SDC 199-1-1. Nav Exos P-643. Tufts College, Institute for Applied Experimental Psychology. Project Designation NR-783-001. Contract N6 onr-199, T.O. 1. SDC Human Eng. Proj. 20-6-1. 1 December 1949.

Hollies, N. R. S., Bogaty, H., Monego, C. J., and Donegan, J. H., Jr. *The Movement of Water Through Apparel Textile Systems*. Textile Series Report No. 96, Textile Clothing and Footwear Division. Natick, Mass.: Quartermaster Research and Development Center, May, 1957.

Kaitz, Evelyn. *Men's Attitudes toward Cotton and Other Fibers in Selected Clothing Items*. USDA Economic Research Service Marketing Research Report No. 1012, October, 1973.

Kaitz, Evelyn, and Stack, Thomas. *Consumers' Buying Practices, Uses, and Preferences for Fibers in Retail Piece Goods*. USDA Economics Research Service. Marketing Research Report No. 1013, February, 1974.

Karlina, K. V. A Study of the Effect of Microlayers of Air on the Insulating Properties of Packets of Clothing Materials. Translated from Russian by B. F. Toms. Orpington, England: Defence Research Information Centre, April, 1972.

Kondratski, E. V. Air Permeability of Fabrics. Orpington, England: Defence Research Information Centre, April, 1972.

Mecheels, J. The Influence of Textile Structure on Its Permeability to Heat and Moisture. Orpington, England: Defence Research Information Centre, July, 1973.

Study of the Thermal Processes for Man-in-Space. Airesearch, Los Angeles. Contract No. NASW-1015. Washington: NASA, 1965.

Taylor, R. F. Investigation of Knitted Fabrics. Kansas City, Mo.: Bendix Corp., January, 1973.

Weiner, Louis I. Evaluation of Comfort Factors in Clothing Design. Army Natick Labs, Mass.: Clothing and Organic Materials Division, May, 1964.

Zimmerman, John, and Gannon, Eleanor. Evaluation of 75/25 Cotton/Dynel Underwear Fabric. Textile Eng. Lab. Report No. 178. Natick, Mass.: Quartermaster Research and Development Center, March, 1957.

Periodicals

AATCC Piedmont Section. "A Study of Oil- and Water-Repellent Surfaces," American Dyestuff Reporter, 52:3, February 4, 1963.

Abrahams, David H. "Durable Press--Review and Outlook," American Dyestuff Reporter, 60:1, 1971, 17-18.

Adamson, Arthur W. "An Adsorption Model for Contact Angle and Spreading," Journal of Colloid and Interface Science, 27:2, June, 1968, 180-187.

Adolph, E. F., and Molnar, G. W. "Exchanges of Heat and Tolerances to Cold in Men Exposed to Outdoor Weather," American Journal of Physiology, 146:4, July 1, 1946, 507-537.

Adolph, E. F. "Heat Exchanges of Man in the Desert," American Journal of Physiology, 123:2, August, 1938, 486-499.

Andreen, J. H., Gibson, J. W., and Wetmore, O. C. "Fabric Evaluations Based on Physiological Measurement of Comfort," Textile Research Journal, 23:1, January, 1953, 11-22.

Andrews, B. A. Kottes, Frick, J. G., Jr., and Gautreaux, Gloria. "Migration of Finishes in Tubular Processing of Knitted Cottons," American Dyestuff Reporter, 62:7, July, 1973, 25-26.

Anon. "Advertising Strategy for U.S. Man-Made Fibers," American Fabrics, 57, Summer, 1962, 90-92.

Anon. "Are All Shirts Alike?" Consumers' Research Magazine, 57:6, June, 1964, 16-20.

Anon. "A Better Hand for Polyester Fabrics," Textile Industries, 138:10, October, 1974, 107, 109, 119.

Anon. "The Big Knitters," American Fabrics, #91, Fall, 1971, 43-50.

Anon. "Blending the Force for Textile Progress," American Fabrics, #66, Winter, 1964-65, 86-91.

Anon. "Bulletin: Interstoff Trevira Filament Yarn with 'Spun' Characteristics," American Fabrics, #100, Spring, 1974, 103.

Anon. "The Chemistry of Clothing," Nature, 184, September 19, 1959, 849-851.

Anon. "Comfort Aspects of High Percentage Cotton Blends," International Dyer and Textile Printer, 140:12, December 21, 1973, 657-658.

Anon. "The Comfort Fibres," Textile Month, December, 1970, p. 91.

Anon. "Cotton Blooms in Naturalspun," American Fabrics, #99, Winter, 1973, 24.

Anon. "Cotton Steps into Pantyhose with New Dimensions in Next-to-the-Skin Comfort," American Fabrics, #100, Spring, 1974, 17.

Anon. "Cotton's Future Reviewed," Textile Manufacturer, 97, August/September, 1971, 339.

Anon. "Cotton's Laboratory in Second Year," Knitting Times, 42:20, May 7, 1973, 33-36.

Anon. "The Difference Between Wovens and Knits," American Fabrics, #90, Spring-Summer, 1971, 64-66.

Anon. "Doubleknit Deluge?" American Fabrics, #91, Fall, 1971, 41.

Anon. "End-Use Engineered Fibers Hold Sway," Textile World, 124:8, August, 1974, 45-52.

Anon. "The Evolution of Textile Fibers," American Fabrics, #82, Spring, 1969, 50-51, 52, 65.

Anon. "Fabrics for All Seasons: Cotton-Blend Knits Fill Comfort Criteria," Textile World, 124:8, August, 1974, 41.

Anon. "Fiber Forecasting: It's Not Easy Anymore," Modern Textiles, 45:9, September, 1974, 26-37.

Anon. "Fibers in the Knit Picture--1967," American Fabrics, #81, Winter, 1968, 77.

Anon. "Geometry and Dimensional Properties of All-Wool Weft-Knitted Structures: Part 1, Basic Weft-Knitted Structural Units: The Plain Loop," Wool Science Review, 40:1, January, 1971.

Anon. "Geometry and Dimensional Properties of All-Wool Weft-Knitted Structures: Part 3, Double Jersey Structures," Wool Science Review, 42, April, 1972, 46-60.

Anon. "Geometry and Dimensional Properties of All-Wool Weft-Knitted Structures," Wool Science Review, 43, April, 1972, 46-60.

Anon. "Growth of Filament Polyester," American Fabrics, Issue 87, Summer, 1970.

Anon. "Injecting Comfort into Nylon," American Fabrics, #18, Summer, 1951, 110.

Anon. "Knits--A Revolution That Succeeded," American Fabrics, #91, Fall, 1971, 35-39.

Anon. "Man and His Thermal Environment," Mechanical Engineering, 79:11, November, 1957, 1029-1036.

Anon. "Man-Made Fibers--1962 World-Wide Production Capacity," American Fabrics, #57, Summer, 1962, 65.

Anon. "Men's T Shirts," Consumer Reports, 36:1, January, 1971, 25-27.

Anon. "Men's Undershirts," <u>Consumer Bulletin</u>, 52:9, September, 1969, 17-20.

Anon. "The Next 100 Issues--Things to Come 1974-2001," <u>American Fabrics</u>, #100, Spring, 1974, 86.

Anon. "Now Even Fabrics Can Breathe Freely," <u>American Fabrics</u>, #13, Spring, 1950, 60.

Anon. "The Physiology of Touch," <u>American Fabrics</u>, #2, Spring, 1947, 107-109.

Anon. "The Physiological Properties of Wool Clothing," Part I, <u>Wool Science Review</u>, #21, August, 1962, 40-50.

Anon. "The Physiological Properties of Wool Clothing," Part II, <u>Wool Science Review</u>, #22, March, 1963, 39-52.

Anon. "The Physiological Properties of Wool Clothing," Part III, <u>Wool Science Review</u>, #23, July, 1963, 1-12.

Anon. "Proposed Standard System of Symbols for Thermal Physiology," <u>Journal of Applied Physiology</u>, 27:7, September, 1969, 439-445.

Anon. "A Selection of SI Units Recommended for Use in the Textile Industry," <u>Textile Institute and Industries</u>, 7:7, July, 1973, 189.

Anon. "Some Comfort Aspects of High Percentage Cotton Blends," <u>Sources and Resources</u>, 1973/6, pp. 9-11.

Anon. "The Sudden Rise of the Knit Dress Shirt," <u>American Fabrics</u>, #92, Winter, 1971-72, 78-82.

Anon. "Staying Cool in Polyester/Rayon Blends," <u>Textile Month</u>, August, 1969, pp. 86-87.

Anon. "A Strategic Approach to Market Development," <u>The Indian Textile Journal</u>, 83:6, March, 1973, 79, 81, 83-84, 87, 89, 91, 93, 95.

Anon. "Surface Modification of Hydrophobic Fibers," <u>Sources and Resources</u>, 1974/6, pp. 3-4.

Anon. "Ten Factors Behind the Knit Boom," <u>American Fabrics</u>, #70, Winter, 1965-66, 46-49.

Anon. "Terms Related to Texturing," <u>American Fabrics</u>, Issue 87, Summer, 1970, 70.

Anon. "Texturing," <u>American Fabrics</u>, Issue 87, Summer, 1970, 63-70.

Anon. "Texturing--Fine and Medium Deniers," Modern Textiles, 48:4, April, 1967, 23-24.

Anon. "Trends in Fiber Usage," America's Textiles Reporter/Bulletin, V:AT-1:7, July, 1972, 50.

Anon. "We Know It Works--Now Let's Make It Beautiful--The Rationale Behind Third Generation Fibers," American Fabrics, #82, Spring, 1969, 47, 49.

Anon. "Whither Natural Fibers," American Fabrics, #52, Spring, 1961, 49-53.

Anon. "Women Going for Cotton Provided the Styling is Right," Textile Month, December, 1973, pp. 44-45.

Anon. "The World of Untextured Filament," American Fabrics, #87, Summer, 1970, 76-78.

Arons, Gilbert N., MacNair, Richard N., and Erickson, Richard L. "Sorption Characteristics of Activated Carbon Fabrics," Textile Research Journal, 43:9, September, 1973, 539-543.

Backer, Stanley. "The Relationship Between the Structural Geometry of a Textile Fabric and Its Physical Properties: Part I, Literature Review," Textile Research Journal, 18:11, November, 1948, 650-658.

Backer, Stanley. "The Relationship Between the Structural Geometry of a Textile Fabric and Its Physical Properties: Part IV, Interstice Geometry and Air Permeability," Textile Research Journal, 21:10, October, 1951, 703-714.

Baxter, S. "Heat and Water Vapour Transfer Through Fabrics," Journal of the Textile Institute, 37, March, 1946, T39-57.

Baxter, S., and Cassie, A. B. D. "The H_2O Repellency of Fabrics: A New H_2O Repellency Test," Journal of the Textile Institute Transactions, 36:4, April, 1945, T67-90.

Baxter, S., and Cassie, A. B. D. "Rate of Propagation of Temperature Change Through Textiles in Humid Atmospheres: Part V, The Comparison of Different Textile Fibres," Transactions Faraday Society, 37:10, October, 1941, 517-523.

Behmann, F. W., and Meissner, H. D. "Movement of Water in Wool: Attempts at Theoretical Estimation of Non-Vaporous Moisture-Conditions in the Range of the Sorption Isotherm," Textile Institute and Industries, 55:4, April, 1964, T217-227.

Behmann, F. W., and Meissner, H. D. "Movement of Water in Wool: 1. Experimental Determination of the Coefficient of Vaporous and Non-Vaporous Moisture-Conduction," Textile Institute and Industries, 55:3, March, 1964, T205-213.

Belding, H. S., and Hertig, B. A. "Sweating and Body Temperatures Following Abrupt Changes in Environmental Temperature," Journal of Applied Physiology, 17:1, January, 1962, 103-106.

Benzinger, T. H. "The Human Thermostat," Scientific American, 204:1, January, 1961, 134-147.

Best, Gordon. "Caring about Comfort," Textile Month, August, 1974, p. 72.

Bille, H. E., Thonig, W., and Schmidt, G. "Comparing Chemical Finishing of Knit and Woven Goods," American Dyestuff Reporter, 61:9, October, 1972, 56-66.

Black, C. P., and Matthew, J. A. "The Physical Properties of Fabrics in Relation to Clothing: Part I--A Review of the Literature," Journal of Textile Institute Transactions, June, 1934, T197-224.

Black, C. P., and Matthew, J. A. "The Physical Properties of Fabrics in Relation to Clothing: Part II--Water Vapour Permeability of Fabrics," Journal of Textile Institute Transactions, June, 1934, T225-240.

Black, C. P., and Matthew, J. A. "The Physical Properties of Fabrics in Relation to Clothing: Part III--Heat Insulation by Fabrics Used as Body Clothing," Journal of Textile Institute Transactions, August, 1934, T-249-276.

Blore, James H. "Combining Yarns on Double Knit Machines," Knitting Times, 42:7, February 12, 1973, 88-90.

Bogaty, Herman, Hollies, Norman R. S., Hintermaier, John C., and Harris, Milton. "The Nature of a Fabric Surface: Thickness-Pressure Relationships," Textile Research Journal, 23:2, February, 1953, 108-114.

Bogaty, Herman, Hollies, Norman R. S., Hintermaier, John C., and Harris, Milton. "Some Properties of Serges Made from Blends of Wool with Acrylic Type Softeners," Textile Research Journal, 23:8, August, 1953, 536-544.

Bolton, C. B., and Simpson, R. E. "Aircrew Functional Clothing," Textile Institute and Industries, 9:2, July, 1971, 42-44.

Brebner, D. F., Kerslake, D. McK., and Waddell, J. L. "The Diffusion of Water Vapour Through Human Skin," Journal of Physiology, 132:1, April 27, 1956, 225-231.

Brookfield, K. F., Fitzpatrick, H. D. N., Jackson, J. F., Matthews, J. B., and Moelwyn-Hughes, E. A. "The Escape of Molecules from a Plane Surface into a Still Atmosphere," Royal Society of London, Proceedings, 190:A1020, June 17, 1947, 59-67.

Brouha, Lucien, Smith, P. E., Jr., and Maxfield, Mary E. "Man and His Thermal Environment--The Industrial Worker," Mechanical Engineering, 82:6, June, 1960, 57-59.

Bruck, O. E. "The Design and Development of Hollow Filaments: A Brief Assessment of Their Potential Advantages," Textile Institute and Industries, 3, May, 1965, 118-121.

Bulmer, M. G., and Forwell, G. D. "The Concentration of Sodium in Thermal Sweat," Journal of Physiology, 132:1, April 27, 1956, 115-122.

Buras, Edmund M., Jr., Goldthwait, Charles F., and Kraemer, Rita M. "Measurement and Theory of Absorbency of Cotton Fabrics," Textile Research Journal, 20:4, April, 1950, 239-248.

Burgess, B. F., Jr. "Tolerance to Acceleration," Mechanical Engineering, 82:6, June, 1960, 62-63.

Burleigh, Edward G., Wakeham, Helmut, Honold, Edith, and Skau, Evold. "Pore-Size Distribution in Textiles," Textile Research Journal, 19:9, September, 1949, 547-555.

Burnip, M. S., and Thomas, I. H. "The Production and Properties of Knitted and Woven Fabrics," Textile Progress, 1:3, September, 1969, 19.

Cannon, S. L., Johnson, R. F., and Meenaghan, G. F. "Analysis of Transport Phenomena Associated with

Convective Drying of a Textile Material, Textile Research Journal, 43:7, July, 1973, 423-427.

Carlene, P. W. "The Moisture Relations of Textiles: A Survey of the Literature," American Dyestuff Reporter, 34:17, August 13, 1945, 322-334.

Cassie, A. B. D. "Characteristics for Warmth in Underwear Fabrics," Journal of the Textile Institute Proceedings, 40:5, May, 1949, 444-453.

Cassie, A. B. D. "Fibres and Fluids," Journal of the Textile Institute, 53:11, November, 1962, 739-745.

Cassie, A. B. D. "Regain of Textiles and Humid Atmosphere Changes," Journal of the Textile Institute Transactions, 31:2, February, 1940, T17-30.

Claybourne, C. Snead, and Zung, Joseph T. "The Effects of Insoluble Films upon the Evaporation Kinetics of Liquid Droplets," Journal of Colloid and Interface Science, 27:1, May, 1968, 25-31.

Clulow, Elaine E. "Permeability and Textiles," Textiles, 3:1, February, 1974, 19-23.

Clulow, Elaine E., and Rees, W. H. "The Transmission of Heat Through Textile Fabrics: Part III, A New Thermal-Transmission Apparatus," Journal of the Textile Institute, 59:6, June, 1960, 285-294.

Cohen, Gabrielle G., and Baker, Cameron A. "Measuring Combined Effects of Moisture Transmission and Thermal Conductivity," American Dyestuff Reporter, 58:21, October 20, 1969, 32-36.

Coplan, Myron J. "Some Moisture Relations of Wool and Several Synthetic Fibers and Blends," Textile Research Journal, 23:12, December, 1953, 897-905.

Cowen, W. "Some Principles of Drying," Journal of the Society of Dyers and Colorists, 55:6, June, 1939, 290-302.

Daniels, H. E. "Propagation of Temperature Changes Through Textiles in Humid Atmospheres: Part IV, Extended Theory of Temperature Propagation Through Textiles," Transactions Faraday Society, 37:10, October, 1941, 506-517.

Darlington, K. D. "Basic Double Knit Structures--Part 1," Knitting Times, 42:7, February 12, 1973, 84-87.

Darlington, K. D. "Basic Double Knit Structures--Part 2," Knitting Times, 42:32, July 30, 1973, 66-71.

Darlington, K. D. "Basic Double Knit Structures--Part 3," Knitting Times, 42:37, September 3, 1973, 36-40.

Darlington, K. D. "Calculation of Warp Run-In Ratios," Knitting Times, 42:9, February 26, 1973, 26-30.

David, H. G. "The Effect of Changing Humidity on the Insulation of Hygroscopic Clothing," Textile Research Journal, 35:9, September, 1965, 820-826.

David, H. G., and Macpherson, R. K. "The Buffering Action of Hygroscopic Clothing," Textile Research Journal, 34:9, September, 1964, 814-816.

Denton, M. J. "Drawing and Texturing of Nylon and Polyester Yarns," Textiles, 3:2, June, 1974, 50-55.

Dichter, Ernest. "Love That Fiber!" American Fabrics, 57, Summer, 1962, 82-84.

Dichter, Ernest. "Needed for the Seventies: A Gourmet Approach to Fibers and Fabrics," American Fabrics, 85, Winter, 1969/70, 69-70.

Dichter, Ernest. "The World Customer," American Fabrics, 60, Spring, 1963, 88-91.

Dillon, J. H. "The Textile Rainbow," American Dyestuff Reporter, 41:3, February 4, 1952, 65.

Dyba, Raymond, and Miller, Bernard. "Evaluation of Wettability from Capillary Rise Between Filaments," Textile Research Journal, 39:10, October, 1969, 962-970.

Dyba, Raymond V., and Miller, Bernard. "Dynamic Measurements of the Wetting of Single Filaments," Textile Research Journal, 40:10, October, 1970, 884-890.

Dyba, Raymond V., and Miller, Bernard. "Dynamic Wetting of Filaments in Solutions," Textile Research Journal, 41:10, October, 1971, 978-983.

Fanger, P. O. "Assessment of Man's Thermal Comfort in Practice," Journal of Industrial Medicine, 30:4, 1973, 313-324.

Feather, Dorothy G. "Physical Testing and Quality Control," Textile Progress, 6:4, December, 1969, 1-94.

Feinberg, Arthur J. "New Frontiers for Knitting," American Fabrics, #81, Winter, 1968, 80-81.

Fisher, C. H. "New Cotton Properties Through Chemical Research," Textile Research Journal, 25:1, January, 1955, 1-7.

Fletcher, Hazel M. "Physical Properties of Knitted Fabrics Made of Natural and Mercerized Carded and Combed Cotton Yarns," Rayon Textile Month, 26, May, 1945, 233-236.

Fonseca, George F. "Heat-Transfer Properties of 10 Underwear-Outerwear Ensembles," Textile Research Journal, 40:6, June, 1970, 553-558.

Fonseca, G. F., and Breckenridge, J. R. "Wind Penetration Through Fabric Systems, Part I," Textile Research Journal, 35:2, February, 1965, 95-103.

Fourt, Lyman, Craig, Allen, and Rutherford, Marjorie B. "Cotton Fibers as Means of Transmitting H_2O Vapor," Textile Research Journal, 27:5, May, 1957, 362-368.

Fourt, Lyman, and Harris, Milton. "Diffusion of Water Vapor Through Textiles," Textile Research Journal, 17:5, May, 1947, 256-263.

Fourt, Lyman, Sookne, Arnold M., Frishman, Daniel, and Harris, Milton. "The Rate of Drying of Fabrics," Textile Research Journal, 21:1, January, 1951, 26-33.

Frevel, L. K., and Kressley, L. J. "Modifications in Mercury Porosimetry," Analytical Chemistry, 35, September, 1963, 1492-1502.

Frick, J. G. "Reducing Laundry Shrinkage in Knitted Cotton and Cotton Blends by Chemical Finishing," Sources and Resources, 7, 1974/5, 20-21.

Frick, J. G., Jr., and Gautreaux, Gloria A. "Increased Opacity in Knit Cotton," Knitting Times, 42:20, May 7, 1973, 32-33.

Frick, J. G., Andrews, B. A. Kottes, Reid, J. David, and Gautreaux, Gloria. "Durable-Press Knits of Cotton and Polyester," The Knitter, 37, April, 1974, 32-36.

Gagge, A. P. "A New Physiological Variable Associated with Sensible and Insensible Perspiration," American Journal of Physiology, 120:2, October, 1937, 277-287.

Gagge, A. P., Burton, A. C., Bayett, H. C. "A Practical System of Units for the Description of the Heat

Exchange of Man with His Environment," Science, 94:2445, November 7, 1941, 428-430.

Gagge, A. P., Winslow, C.-E. A., and Herrington, L. P. "The Influence of Clothing on the Physiological Reactions of the Human Body to Varying Environmental Temperatures," American Journal of Physiology, 124:1, October, 1938, 30-50.

Gan, Ludwik R. "Knitter's Role in Producing Dimensionally Stable Knitted Wool Garments," Knitted Outerwear Times, 36:42, October 9, 1978, 18-25.

Gay, Don W. "Knitwear in the 1970's: The Customer's Viewpoint," Knitting Times, 42:20, May 7, 1973, 37-38.

Ghosh, R. C. "Comfort of Clothing," Silk and Rayon Industries of India, 15, March, 1972, 114-116.

Givoni, Baruch, and Goldman, Ralph F. "Predicting Metabolic Energy Cost," Journal of Applied Physiology, 30:3, March, 1971, 429-433.

Glaser, E. M., and Newling, P. S. B. "The Control of Body Temperature in Thermal Balance," Journal of Physiology, 137:I-II, June 18, 1957, 1-11.

Goldman, Ralph F. "Physiologic Effects of Wearing a Rubberized Net Overgarment in the Heat," Textile Research Journal, 33:9, September, 1963, 764-766.

Goodings, A. C. "Air Flow Through Textile Fabrics," Textile Research Journal, 34:8, August, 1964, 713-724.

Gotshal, Yehezkiel, Rebenfeld, Ludwig, and White, Howard J., Jr. "The Absorption of Cation Surfactants by Cellulosic Materials: II. The Effects of Esterification of the Carboxyl Groups in the Cellulosic Substrates," Journal of Colloid Science, 14:6, December, 1959, 619-629.

Grant, James N., Andrews, Frederick R., and Weiss, Louis C. "Physical Properties of Cotton Treated by Pad-Dry-Cure, Mild-Cure, Poly-Set, and Wet-Fix Processes," Textile Research Journal, 41:1, January, 1971, 44-51.

Grant, William H. "What the Common Market Can Learn from American Experience in Mass-Marketing Man-Made Fibers," American Fabrics, #57, Summer, 1962, 85-87.

Greenwood, K., and Rees, W. H. "Letters to the Editor, Problems of Protection and Comfort in Modern Apparel Fabrics--Reply," Journal of the Textile Institute, 62:1, January, 1971, 58-59.

Greenwood, K., Rees, W. A., and Lord, Joan. "Problems of Protection and Comfort in Modern Apparel Fabrics," Journal of the Textile Institute, 62:1, January, 1971, 56-59.

Gregory, James. "The Absorption, Transmission, and Reflection of Radiant Heat by Fibrics," Journal of the Textile Institute Transactions, 21, 1930, T57-65.

Gregory, James. "The Transference of Moisture Through Fabrics," Journal of the Textile Institute Transactions, 21, 1930, T66-84.

Grosberg, P. "Cover Factor and Cover (Proposed Definitions)," Textile Institute and Industries, 10, September, 1972, 262.

Haisman, M. F., and Goldman, R. F. "Physiological Evaluations of Armoured Vests in Hot-Wet and Hot-Dry Climates," Ergonomics, 17:1, January, 1974, 1-12.

Hamlin, Charles, and Worner, Ruby K. "Properties of Knit Underwear Fabrics of Various Constructions," Journal of Research, National Bureau of Standards, 13, September, 1934, 311-329.

Hardy, H. B., Jr., Ballou, T. W., and Wetmore, O. C. "Prediction of Equilibrium Thermal Comfort from Physical Data on Fabrics," Textile Research Journal, 23:1, January, 1953, 1-10.

Heitmiller, Richard F. "The Force of Change," Modern Textiles, 53:9, September, 1972, 19-24.

Hellon, R. F., Jones, R. M., Macpherson, R. K., and Weiner, J. S. "Natural and Artificial Acclimatization to Hot Environments," Journal of Physiology, 132:3, June 28, 1956, 559-576.

Hendler, Edwin, and Hardy, James D. "Man and His Thermal Environment," Mechanical Engineering, 81:8, August, 1959, 69-70.

Henschel, Austin, and Hanson, H. E. "Heat Stress in the Desert," Mechanical Engineering, 82:6, June, 1960, 59-62.

Hertel, K. L., and Craven, C. J. "Cotton Fineness and Immaturity as Measured by the Arealometer," Textile Research Journal, 21:11, November, 1951, 765-774.

Hock, Charles W., Sookne, Arnold M., and Harris, Milton. "Thermal Properties of Moist Fabrics," *Journal of Research, National Bureau of Standards*, 32, May, 1944, 229-252.

Hock, Charles W., Sookne, Arnold M., and Harris, Milton. "Thermal Properties of Moist Fabrics," *American Dyestuff Reporter*, 33:10, May 8, 1944, 206-209.

Hoffman, R. M. "Measuring the Aesthetic Appeal of Textiles," *Textile Research Journal*, 35:5, May, 1965, 428-434.

Hoffman, R. M., and Beste, L. F. "Some Relations of Fiber Properties to Fabric Hand," *Textile Research Journal*, 21:2, February, 1951, 66-77.

Hoffman, R. M., and Peterson, R. W. "Engineering of Fabrics from Blends with Synthetic Fibres," *Journal of the Textile Institute*, 49:8, August, 1958, 418-432.

Hoge, Harold J., and Fonseca, George F. "The Thermal Conductivity of a Multilayer Sample of Underwear Material under a Variety of Experimental Conditions," *Textile Research Journal*, 34:5, May, 1964, 401-410.

Hollies, Norman R. S., Bogaty, Herman, Hintermaier, John C., and Harris, Milton. "The Nature of a Fabric Surface: Evaluation by a Rate of Cooling Method," *Textile Research Journal*, 23:11, November, 1953, 763-769.

Hollies, R. S., and Bogaty, Herman. "Some Thermal Properties of Fabrics: Part II, The Influence of Water Content," *Textile Research Journal*, 35:2, February, 1965, 187-190.

Hollies, Norman R. S., Kaessinger, Martha M., Watson, Barbara S., and Bogaty, Herman. "Water Transport Mechanisms in Yarns and Fabrics: Part II, Capillary-Type Penetration in Yarns and Fabrics," *Textile Research Journal*, 27:1, January, 1957, 8-13.

Hollies, N. R. S., and Krasny, J. F. "The Development of Quick Drying, Easy Care Cotton Fabrics," *American Dyestuff Reporter*, 55:26, December 19, 1966, 17-19.

(Hollies, N. R. S.) Anon. "The Elements of Ordinary Clothing Comfort," Sources and Resources, 6, 1973/4, 10-11.

Honold, Edith, and Grant, James N. "Sorptions in Cottons Progressively Cross-Linked in the Pad-Dry-Cure, Mild-Cure, Poly-Set, or Wet-Fix Process," Textile Research Journal, 41:1, January, 1971, 52-56.

Jones, Brian. "Durable Press--What Price Cotton?" American Dyestuff Reporter, 60:1, January, 1971, 19-20.

Jones, Charles W. "Fibers and Yarns: Present Problems and Future Prospects," Knitting Times, 42:21, May 14, 1973, 60-62.

Jung, Mary Ann. "Cotton Incorporated's Natural Blend Double Knit Going Commercial," Knitting Times, 43:19, May 6, 1974, 29-30.

Kanagy, Joseph R. "Adsorption of Water Vapor by Untanned Hide and Various Leathers at 100°F.," Journal of Research, National Bureau of Standards, 38, January, 1947, 119-128.

Kärrholm, M., Bostwick, C. O., and Silén, Gösta. "Influence of Temperature and Moisture Regain Changes on the Wrinkling of Wool Fabrics," Textile Research Journal, 39:8, August, 1969, 795-796.

Kasimir, J. J. "Chemical Finishing of Knits," American Dyestuff Reporter, 63:4, April, 1974, 27-29.

King, G., and Cassie, A. B. D. "Propagation of Temperature Changes Through Textiles in Humid Atmospheres: Part I, Rate of Absorption of Water Vapor by Wool Fibres," Faraday Society, 36, 1940, 445-465.

Knapton, J. J. F., Ahrens, F. J., Ingenthron, W. W., and Fong, W. "The Dimensional Properties of Knitted Wool Fabrics: Part I, The Plain-Knitted Structure," Textile Research Journal, 38:10, October, 1968, 999-1012.

Knapton, James J. F. "The Dynamics of Weft-Knitting (Further Theoretical and Mechanical Analyses)," Textile Research Journal, 38:9, September, 1968, 914-924.

Knapton, J. J. F., Richards, S., and Fong, W. "The Dimensional Properties of Knitted Wool Fabrics: Part III, The Plain-Knit Structure in Machine-Washing and Tumble-Drying," Textile Research Journal, 40:6, June, 1970, 543-553.

Knapton, J. J. F. "Factors Affecting the Stable Dimensions of Double-Jersey Structures," Journal of the Textile Institute, 65:6, 1974, 293-299.

Knapton, J. J. F. "Knitting High-Quality Double-Jersey Cloth (I)," General Factors Controlling Efficiency of Manufacture, Textile Institute and Industries, 10, February, 1972, 39-42.

Knapton, J. J. F. "Knitting High-Quality Double-Jersey Cloth (II)," Recommendations for Optimum Run-In and Run-In Ratio Conditions," Textile Institute and Industries, 10, March, 1972, 68-72.

Knapton, J. J. F. "Knitting High-Quality Double-Jersey Cloth (III)," The Influence of Yarn Tex and Fabric Structure on Knitting Performance and Fabric Dimensions, Textile Institute and Industries, 10, April, 1972, 103-106.

Knapton, J. J. F. "Knitting High-Quality Double-Jersey Cloth (IV)," Dimensional Properties of the Punto-di-Roma Structure, Textile Institute and Industries, 12:1, January, 1974, 345-348.

Knapton, J. J. F. "The Geometry and Dimensional Properties of Weft Knitted Fabric Constructions," Knitted Outerwear Times, 36:41, October 2, 1967, 48-53.

Knapton, J. J. F., and Fong, W. "The Dimensional Properties of Knitted Wool Fabrics: Part VI, Some Observations of Completely-Relaxed Fabric Geometry," Textile Research Journal, 41:11, November, 1971, 894-899.

Knight, B. A., Hersh, S. P., and Brown, P. "Moisture Characteristics of Some Knit Fabrics Made from Blend Yarns," Textile Research Journal, November, 1970, pp. 843-851.

Korzenik, Sidney S. "Analysis and Prospect--Annual Report," Knitting Times, 43:20, May 13, 1974, 50-72.

Latham, Barbara J. "The Structure of Shirting Fabrics in Relation to Comfort in Wear," Clothing Research Journal, 1:2, 1973, 3-27.

Leach, L. L. "Fibres, Fabrics, and Body Comfort," Canadian Textile Journal, 74:9, May 3, 1957, 59-65.

Leaf, G. A. V. "Letters to the Editor--The Thickness and Bulk Density of Plain-Knitted Fabrics," Journal of the Textile Institute, 62:10, October, 1971, 585-586.

Lennox-Kerr, Peter. "Micro-Climate--Is It Japperwocky?" Textile Industries, 135:2, February, 1971, 75-80, 82.

Levell, C. A., Breckenridge, J. R., and Goldman, R. F. "Effect of Laundering and Starching on Insulation and Vapor Permeability of Standard Fatigues," Textile Research Journal, 40:3, March, 1970, 281-285.

Lewis, James. "Stain Repellent Finishes for Wool, Part 1," Wool Science Review, 48, March, 1974, 42-58.

Lichstein, B. M. "Demand Wettability: A New Method for Measuring Absorbency Characteristics of Fabrics," Sources and Resources, 1974/3, pp. 30-32.

Loeb, L. "Water Retention by Cotton Fabric during Centrifuging," Textile Research Journal, 38:7, July, 1963, 521-526.

Lundgren, Harold P. "New Concepts in Evaluating Fabric Hand," Textile Chemist and Colorist, 1:1, January 1, 1969, 35-45.

Manjrekar, T. G. "Determination of Moisture in Textiles by Thermogravimetric Analysis," Textile Chemist and Colorist, 5:9, September, 1973, 186-187.

Mark, Herman. "What Next in Man-Made Fibers?" Textile Chemist and Colorist, 4:1, January, 1972, 42-46.

Martin, H. De V., and Goldman, R. F. "Comparison of Physical, Biophysical and Physiological Methods of Evaluating the Thermal Stress Associated with Wearing Protective Clothing," Ergonomics, 15:3, May, 1972, 337-342.

Martin, W. Baine, Jr. "Texturizing," Knitting Times, 42:21, May 14, 1973, 66-67.

Maurer, Rolf. "Finishing and Refinishing of Knit and Textured Woven Polyester," Canadian Textile Journal, 91:6, June, 1974, 99-104.

Mayer, Rayomond P., and Stowe, Robert A. "Mercury Porosimetry: Filling of Toroidal Void Following Breakthrough Between Packed Spheres," Journal of Physical Chemistry, 70:12, December, 1966, 3867-3873.

McIntyre, D. A., and Griffiths, I. D. "Subjective Response to Radiant and Convective Environments," Environmental Research, 5:4, December, 1972, 471-487.

McKissick, Ellison S., Jr. "Can Cotton Share in Textile Growth of the 70s?" <u>Cotton International</u>, 38:21, 1971, 20-21.

Mecheels, Jurgen. "Physiological Properties of Knitgoods," <u>Hosiery Times</u>, 38:428, January, 1965, 43-84.

Mecheels, Jurgen. "Physiological Wearing Properties of Knitted Fabrics," <u>Knitted Outerwear Times</u>, 34:25, February 8, 1965, 25, 73, 75, 76, 81.

Mecheels, Jurgen H., Demeler, Renate M., and Kachel, Eberhard. "Moisture Transfer Through Chemically Treated Cotton Fabrics," <u>Textile Research Journal</u>, 16:4, April, 1966, 375-384.

Mecheels, O. "Quelques Aspects de la Phipiologie au rêtement," <u>Industrie Textile</u>, 904, 1962, 549-556.

Mehrtens, David G., and McAlister, Kenneth C. "Fiber Properties Responsible for Garment Comfort," <u>Textile Research Journal</u>, 32:8, August, 1962, 658-665.

Miller, E. E., and Miller, R. D. "Physical Theory for Capillary Flow Phenomena," <u>Journal of Applied Physics</u>, 27:4, April, 1956, 324-332.

Minor, Francis, and Schwartz, Anthony. "The Migration of Liquid in Textile Assemblies: Part III, The Behavior of Liquid on Single Textile Fibers," <u>Textile Research Journal</u>, 29:12, December, 1959, 940-949.

Minor, Francis, Schwartz, Anthony, and Buckles, Laurence C. "The Migration of Liquid in Textile Assemblies: Part II, The Wicking of Liquid in Yarns," <u>Textile Research Journal</u>, 29:12, December, 1959, 931-939.

Minor, F. W., Anthony, M., Schwartz, A., Buckles, L. C., Wulkon, E. A., Parks, Melvin P., and Fielding, George H. "The Migration of Liquid in Textile Assemblies: Part IV, Penetration of Fabrics by Liquid," <u>Textile Research Journal</u>, June, 1961, 525-539.

Minor, Francis W., Sookne, Arnold M., Simpson, J. E., and Harris, Milton. "The Use of Water Permeability Measurements on Swelling-Type Fabrics," <u>Textile Research Journal</u>, 16:11, November, 1946, 539-544.

Mitu, S. "Absorbtia Umiditatii De Catre Produsele de Imbracaments," <u>Industria Textile</u> (Roumania), 23:1, 28-32.

Mole, R. "The Relative Humidity of the Skin," Journal of Physiology, 107:4, September 30, 1948, 399-411.

Moncrieff, R. W. "Fibre Physiological Research," International Dyer, 146:11, December 3, 1971, 632-634.

Morris, G. J. "Thermal Properties of Textile Materials," Journal of the Textile Institute, 44, 1953, T449-476.

Morris, W. J. "Polyester Fibres," Textiles, 3:2, June, 1974, 30-35.

Mueller, Karl. "Cotton Incorporated's Approach to Product Development," Modern Textiles, 54:1, January, 1973, 76-78.

Mueller, Karl. "Open-end Spun Yarns: Their Impact on the Woven and Knitted Fabric Markets," Modern Textiles, 55:9, September, 1974, 64-66.

Nakayana, Teruo; Eisenman, Joseph S., and Hardy, James D. "Single Unit Activity of Anterior Hypothalamus during Local Heating," Science, 134:3478, August 25, 1961.

Neale, S. M., and Stringfellow, W. A. "The Primary Sorption of Water by Cotton," Transactions Faraday Society, 37:10, October, 1941, 525-532.

Neiman, R. S. (trans.). "Porous and Hollow Viscose Rayons for Heat Insulation and Textile Purposes, Fibre Chemistry, Russian original #4, July-August, 1973; translation published December, 1973, pp. 448-451.

Nelson, Norton, Eichna, Ludwig W., Horvath, Steven M., Shelley, Walter B., and Hatch, T. F. "Thermal Exchanges of Man at High Temperatures," American Journal of Physiology, 151:2, December 19, 1947, 626-651.

Newburgh, L. H., and Johnston, Margaret Woodwell. "The Insensible Loss of Water," Physiological Reviews, 22:1, January, 1942, 1-18.

Newns, A. C. "The Methods of Determining the Water Vapour Permeability of Laminae--A Review of the Literature," Journal of the Textile Institute, 41:8, August, 1950, T269-308.

Nice, G. R. "Apparatus for the Measurement of the Water-Vapour Permeability of Leather," Society of Leather Trades Chemists, Journal, 35, 1951, 17-20.

Nordon, P., Mackay, B. H., Downes, J. G., and McMahon, G. B. "Sorption Kinetics of H_2O Vapor in Wool Fibers: Evaluation of Diffusion Coefficients and Analysis of Integral Sorption," Textile Research Journal, 30:10, October, 1960, 761-770.

Northern Piedmont Section. 1971 Intersectional Technical Paper Competition. "The Effect of Repeated Application of Home Softeners upon Absorbency and Other Properties of Terry Towels," Textile Chemist and Colorist, 4:1, January, 1972, 49-54.

Nossar, M. S., Chaikin, M., and Datyner, A. "33--High Intensity Drying of Textile Fibres: Part III, The Effect on the Rate of Drying of Non-Uniformities in Fibre and Moisture Distribution within a Bed of Fibres or Yarns," Journal of the Textile Institute, 65:6, 1974, 300-306.

Nutting, T. S. "The Next Twenty-five Years in Clothing Fibres," Clothing Research Journal, 21:5, 1973, 333, 334, 337, 338.

Odling, M. F. "The Economics of Knitting," The Hosiery Trade Journal, #5, January, 1972, 76-79.

Ogden, L. W., and Rees, W. H. "Measurement of Temperature and R.H. on the Skin and Clothing of a Human Subject," Journal of the Textile Institute Transactions, 38:11, November, 1947, T371-386.

Okada, Akira. "Forthcoming New Fiber Material," Japan Textile News, #206, January, 1972.

Olofsson, B. "A General Model of a Fabric as a Geometric-Mechanical Structure," Journal of the Textile Institute, 55:11, November, 1964, T541-557.

Pace, Duane. "Textured Yarn Processing," America's Textiles Reporter/Bulletin, 98:2, February, 1972, 20-32.

Papero, P. V., Kubu, E., and Roldan, L. "Fundamental Property Consideration: Ink Tailoring a New Fiber," Textile Research Journal, 37:10, October, 1967, 823-833.

Peirce, F. T. "A Two-Phase Theory of the Absorption of H_2O Vapour by Cotton Cellulose," Journal of the Textile Institute, 120, 1929, T133-150.

Peirce, F. T. "Geometrical Principles Applicable to the Design of Functional Fabrics," Textile Research Journal, 17:3, March, 1947, 123-146.

Peirce, F. T., and Rees, W. H. "The Transmission of Heat Through Textile Fabrics--Part II," Journal of the Textile Institute, 37, September, 1946, T181-204.

Peirce, F. T., Rees, W. H., and Ogden, L. W. "Measurement of the Water Vapour Permeability of Textile Fabrics," Journal of the Textile Institute, 36:7, July, 1945, T169-176.

Penner, S. E., and Robertson, A. F. "Flow Through Fabric-Like Structures," Textile Research Journal, 21:11, November, 1951, 775-788.

Peters, John P. "Water Exchange," Physiological Review, 24:4, October, 1944, 491-509.

Postle, R. "Letters to the Editor--The Thickness and Bulk Density of Plain-Knitted Fabrics--Reply," Journal of the Textile Institute, 62:10, October, 1971, 586-588.

Postle, R., and Munden, D. L. "Analysis of the Dry-Relaxed Knitted-Loop Configuration: Part I, Two-Dimensional Analysis," Journal of the Textile Institute, 58:8, August, 1967, 329-351.

Postle, R., and Munden, D. L. "Analysis of the Dry-Relaxed Knitted-Loop Configuration: Part II, Three-Dimensional Analysis," Journal of the Textile Institute, 58:8, August, 1967, 352-365.

Preston, J. M., and Chen, J. C. "Some Aspects of the Drying and Heating of Textiles: Part I, The Moisture in Fabrics," Journal of the Society of Dyers and Colorists, 62:12, December, 1946, 361-364.

Preston, J. M., and Nimkar, M. V. "Capillary Phenomena in Assemblies of Fibres," Journal of the Textile Institute, 43:8, August, 1952, T402-422.

Preston, J. M., Nimkar, M. V., and Gundavda, S. P. "Capillary and Imbibed Water in Assemblies of Moist Fibres," Journal of the Textile Institute, 42:2, February, 1951, T79-90.

Price, R. A. "Trends in Apparel Fabrics," Textiles, 3:2, June, 1974, 45-49.

Quinson, J. F., Escoubes, M., Chauchard, J., Chabert, B., and Soulier, J. P. "Etude Microcalorimetrique de la sorption d'eau sur des fibres et des grains de polyterephtalate d'ethylene-glycol," Journal de Chimie Physique et de Physico Chimie Biologique, Tome 69, N 7-8, Juillet-Aout, 1972, pp. 1143-1148.

Rader, Charles A., and Schwartz, Anthony M. "The Migration of Liquids in Textile Assemblies: Part V, Two-Component and Two-Phase Liquid Systems," Textile Research Journal, 32:2, February, 1962, 440-453.

Rawson, Robert, and Randall, Walter C. "Vascular and Sweating Responses to Regional Heating of the Body Surface," Journal of Applied Physiology, 16:6, November, 1961, 1006-1010.

Rees, Howard. "The Heat of Absorption of H_2O by Cellulose," Journal of the Textile Institute Transactions, 39:11, November, 1948, T351-367.

Rees, Howard W. "The Transmission of Heat Through Fabrics," Journal of the Textile Institute Transactions, 32:8, August, 1941, T149-166.

Rees, W. H. "The Protective Value of Clothing," Journal of the Textile Institute, 37, July, 1946, T132-153.

Rees, W. H. "Some Experiments on the Evaporation of Water from a Plane Surface," Journal of the Textile Institute, 36:7, July, 1945, T165-168.

Rees, W. H. "What Makes a Comfortable Fabric?" Textile Month, August, 1969, pp. 59-61.

Reichman, Charles (ed.). "1974-5 Buyers' Guide Directory," Knitting Times, September 23, 1974.

Reichman, Charles. "Cotton in Knit Underwear: A Report," Knitted Outerwear Times, 38:20, May 12, 1969, 21-25.

Reichman, Charles. "Soaring Prices Undermining Cotton's Position in Knits," Knitting Times, 43:19, May 6, 1974, 27-28.

Reichman, Charles. "Surfactants: Surface-Active Agents with Versatile Applications," Knitting Times, 42:11, March 12, 1973, 31.

Reichman, Charles. "The Anatomy of a Circular Yardgoods Machine--Part 1," Knitting Times, August 14, 1974, pp. 35-45.

Renbourn, E. T. "The Physiology of Clothing," Ciba Review, 1964/4.

Renbourn, E. T., and Rockwell, E. C. "Fibres, Films, and Fabrics for Military Use," Journal of the Textile Institute, 54:1, February, 1963, 180-186.

Research Subcommittee, Southeastern Section, AATCC. "Capillary Rise Related to Soil Release Performance of Durable Press Fabrics," Textile Chemists and Colorists, 1:8, April 9, 1969, 202-207.

Robertson, A. F. "Air Porosity of Open-Weave Fabrics: Part I, Metallic Meshes," Textile Research Journal, 20:12, December, 1950, 838-844.

Robertson, A. F. "Air Porosity of Open-Weave Fabrics: Part II, Textile Fabrics," Textile Research Journal, 20:12, December, 1950, 844-857.

Robinson, Sid, and Robinson, Aline H. "Chemical Composition of Sweat," Physiological Review, 34:2, April, 1954, 202-220.

Robinson, Sid, Turrell, E. S., and Gerking, S. D. "Physiologically Equivalent Conditions of Air Temperature and Humidity," American Journal of Physiology, 143:1, January, 1945, 21-32.

Rodwell, E. C., Renbourn, J. Greenland, and Kenchington, K. W. L. "An Investigation of the Physiological Value of Sorption Heat in Clothing Assemblies," Journal of the Textile Institute, 56:11, November, 1965, T624-645.

Rootare, Hillar M., and Prenzlow, Carl F. "Surface Areas from Mercury Porosimeter Measurements," Journal of Physical Chemistry, 71:8, July, 1967, 2733-2736.

Rowland, Stanley P. "The Mechanisms of Durable Press," Textile Chemists and Colorists, 4:9, September, 1972, 204-233, 211-240.

Saunders, Arthur M. "Selling Becomes Marketing under the Impact of the Man-Made Fibers," American Fabrics, 57, Summer, 1962, 88-89.

Schiefer, Herbert F. "The Compressometer: An Instrument for Evaluating the Thickness, Compressibility, and Compressional Resilience of Textiles and Similar Materials," Journal of Research, National Bureau of Standards, 10:6, June, 1933, 705-713.

Schiefer, Herbert F., Cleveland, Richard S., Porter, John W., and Miller, Joshua. "Effect of Weave on the Properties of Cloth," Journal of Research, National Bureau of Standards, 7, October, 1933, 441-451.

Schiefer, Herbert F., Stevens, Hazel Tharp, Mack, Pauline Beery, and Boyland, Paul M. "A Study of the Properties of Household Blankets," Journal of Research, National Bureau of Standards, 32, June, 1944, 261-284.

Schofield, F. "Communication--Porosity: A Primary Property of Textiles. V--Porosity of Fabrics and Penetration Problems," Journal of the Society of Dyers and Colorists, 47:6, June, 1931, 166-168.

Schwartz, Anthony M. "Capillarity Theory and Practice," Industrial and Engineering Chemistry, 61:1, January, 1969, 10-21.

Schwartz, Anthony M., and Minor, Francis W. "A Simplified Thermodynamic Approach to Capillarity: I, Application to Flow in Capillary Channels," Journal of Colloid Science, 14:6, December, 1959, 572-583.

Schwartz, Anthony M., and Minor, Francis. "A Simplified Thermodynamic Approach to Capillarity: II, Applications to Contact Angle and Spreading Phenomena," Journal of Colloid Science, 14:6, December, 1959, 584-597.

Seaman, R. E. "Barrier Properties of an Air Permeable, Fine-Fiber Spunbonded Polyethylene Sheet," Sources and Resources, 1974/3, pp. 25-26.

Seaman, R. E. "The Measurement of Fabric Thickness," Textile Research Journal, 23:4, April, 1953, 262-266.

Segall, G. H. "A Theory of Water Resistant Fabrics," Textile Research Journal, 22:11, November, 1952, 738, 739.

Segall, William M. "What's Ahead for Cotton?" Canadian Textile Journal, 85, April 26, 1968, 51-53.

Sexsmith, Frederick H., and White, Howard J., Jr. "The Absorption of Cationic Surfactants by Cellulosic Materials: I, The Uptake of Cation and Anion by a Variety of Substrates," Journal of Colloid Science, 14:6, December, 1959, 498-619.

Sexsmith, Frederick, and White, Howard J., Jr. "The Absorption of Cationic Surfactants by Cellulosic Materials: III, A Theoretical Model for the Absorption

Process and a Discussion of Maxima in Absorption Isotherms for Surfactants," Journal of Colloid Science, 14:6, December, 1959, 630-639.

Shinn, W. E. "An Engineering Approach to Jersey Fabric Construction," Textile Research Journal, 25:3, March, 1955, 270-277.

Sieminski, M. A., and Hotte, G. H. "The Permeability of Fabrics," Rayon Textile Month, 26, January, 1945, 68-70.

Slowinske, George A. "The Evaluation of Textile Finishes," American Dyestuff Reporter, 30:1, January, 1941, 6-14.

Smirfitt, J. A. "The Production and Properties of Weft-Knitted Fabrics," Textile Progress, 5:2, 1973, 1-113.

Smith, P. A. "Yarn Production and Properties," Textile Progress, 1:2, June, 1969, 1-121.

Song, H., and Turner, H. "Some Aspects of the Geometry of Simple Rib-Tuck Weft-Knitted Wool Fabrics," Textile Research Journal, 38:5, May, 1968, 481-487.

Sookne, Arnold M., Minor, Francis W., Simpson, J. E., and Harris, Milton. "A Drop-Penetration Apparatus for Evaluating Water Repellent Fabrics," American Dyestuff Reporter, 35:12, June 17, 1946, 295-308.

Sorensen, Tormod, and Hog, Jorgen. "Determination of Temperature and Moisture Regain Changes in Wool Fabrics Wrinkled during Wear," Textile Research Journal, 39:8, August, 1969, 793-795.

Speakman, J. B., and Chamberlain, H. H. "The Thermal Conductivity of Textile Materials and Fabrics," Journal of the Textile Institute Transactions, 21, 1930, T29-56.

Spencer-Smith, J. L. "The Buffering Effect of Hygroscopic Clothing," Textile Research Journal, 36, September, 1966, 855-856.

Spencer-Smith, J. L. "Letters to the Editor--Problems of Protection and Comfort in Modern Apparel Fabrics," Journal of the Textile Institute, 62:1, January, 1971, 56-58.

Steele, Richard. "Factors Affecting the Drying of Apparel Fabrics: Part I, Drying Behavior," Textile Research Journal, 28:2, February, 1958, 136-144.

Steele, Richard. "Factors Affecting the Drying Behavior of Apparel Fabrics: Part II, Capillary Size Distribution," Textile Research Journal, 28:2, February, 1958, 144-147.

Steiger, Fred H., and Kapur, Chandra. "The Absorption of Liquids by Compressed Fiber Systems," Textile Research Journal, 42:8, August, 1972, 443-449.

Stuart, I. M. "Some Developments of Olofsson's Theory of Woven Fabric Structure," Textile Research Journal, 39:9, September, 1969, 844-850.

Suh, Moon Won. "A Study of the Shrinkage of Plain Knitted Cotton Fabric, Based on the Structural Changes of the Loop Geometry Due to Yarn Swelling and Deswelling," Textile Research Journal, 37:5, May, 1967, 417-431.

Tanquary, A. C. "Hollow Fibers," Bulletin, Southern Research Institute, 26:1, Summer, 1973, 10-13.

Teitlebaum, A., and Goldman, Ralph F. "Increased Energy Cost with Multiple Clothing Layers," Journal of Applied Physiology, 32:6, June, 1972, 743-744.

Toureille, D. "Comportement des textiles au tunnel de finition," Textiles Chimiques, 28:5, May, 1972, 38-44.

Urquhart, Alexander Robert, and Williams, Alexander Mitchell. "The Moisture Relations of Cotton: The Taking Up of H_2O by Raw and Soda-Boiled Cotton at 20°C.," Journal of the Textile Institute, 15, 1924, T559-572.

Vasti, Assunta. "The Insensible Water Loss Through the Skin," American Journal of Physiology, 102:1, October 1, 1932, 60-70.

Verburg, G. B., Frick, J. G., Jr., and Reid, David J. "Induced Shrinkage in Durable-Press Knitted Fabrics," The Knitter, 35, November, 1971, 25-28.

Verburg, G. B., Frick, J. G., Jr., and Reid, David. "Shrinkage Control of Durable Press Knitted Cottons," American Dyestuff Reporter, 62:7, July, 1973, 26.

Vokac, Z., Kopke, V., and Keül, P. "Assessment and Analysis of the Bellows Ventilation of Clothing," Textile Research Journal, 43:8, August, 1973, 474-482.

Vokac, Z., Kopke, V., and Keül, P. "Effect of Cooling of Peripheral Parts of the Body on General Thermal Comfort," Textile Research Journal, 41, October, 1971. 827-833.

Vokac, Z., Kopke, V., and Keül, P. "Evaluation of the Properties and Clothing Comfort of the Scandinavian Ski Press in Wear Trials," *Textile Research Journal*, 42, February, 1972, 125-134.

Wakeham, Helmut, and Spicer, Nancy. "Pore-Size Distribution in Textiles--A Study of Windproof and Water Resistant Cotton Fabrics," *Textile Research Journal*, 19:11, November, 1949, 703-710.

Watkins, Susan M. "New Careers for Home Economists: Designing Functional Clothing," *Journal of Home Economics*, 66:7, November, 1974, 33-38.

Webb, Reiter H., Jr. "Cotton: Present Problems and Future Prospects," *Knitting Times*, 42:20, May 7, 1973, 30-32.

Weigmann, Hans-Dietrich, Scott, Marjie G., and Rebenfeld, Ludwig. "Relation of Fiber and Fabric Properties of Durable-Press Cottons," *Textile Research Journal*, 39:5, May, 1969, 460-470.

Weiner, Louis I. "Relationship of Moisture Vapor Transmission to the Structure of Textile Fabrics," *Textile Chemists and Colorists*, 2:22, November 4, 1970, 378-385.

Welfers, E. "Bekleidungsphysiologische Untersuchungen an Web-und Maschenware zur Ermittlung des Tragekomforts," *Textilverdulung*, March, 1971, pp. 150-165.

Wenzel, Robert N. "Resistance of Solid Surfaces to Wetting by Water," *Industrial and Engineering Chemistry*, 28:8, August, 1936, 988-994.

Wheatley, B. "RM 6-8 VS-W Weft Insertion Machine," *Knitting Times*, 42:15, April 9, 1973, 30-38.

Whelan, Margaret E., MacHattie, Lloyd E., Goodings, A. C., and Turl, L. H. "The Diffusion of Water Vapor Through Laminae with Particular Reference to Textile Fabrics," *Textile Research Journal*, 25:3, March, 1955, 197-223.

Whelan, Margaret E., MacHattie, Lloyd E., Goodings, A. C., and Turl, L. H. "The Diffusion of Water Vapor Through Laminae with Particular Reference to Textile Fabrics," *Textile Research Journal*, 25:3, March, 1955, 197-205.

Williams, R. C. G., and Leaf, G. A. V. "Letters to the Editor--The Thickness of Plain-Knitted Fabrics," Journal of the Textile Institute, 65:7, 1974, 380-383.

Winch, Allen R. "Theoretical Analysis of Rate of Liquid Absorption by Capillary Absorbing Media," Textile Research Journal, 29:3, March, 1959, 193-199.

Winslow, C. E. A., Herrington, L. P., and Gagge, A. P. "The Relative Influence of Radiation and Convection upon the Temperature Regulation of the Clothed Body," American Journal of Physiology, 124:1, October, 1938, 51-61.

Winslow, C. E. A., Herrington, L. P., and Gagge, A. P. "Physiological Reactions of the Human Body to Various Atmospheric Humidities," American Journal of Physiology, 120:2, October, 1937, 288-299.

Winslow, C. E. A., Herrington, L. P., and Gagge, A. P. "Physiological Reactions of the Human Body to Varying Environmental Temperatures," American Journal of Physiology, 120:1, September 1, 1937, 1-22.

Wolfgang, William. "A Primer on Fabric Properties, Part I," Western Apparel Industry, 31:1, January, 1973, 17, 67, 79.

Wolfgang, William. "A Primer on Fabric Properties, Part II," Western Apparel Industry, 31:2, February, 1973, 146-150.

Woodcock, A. H. "Moisture Transfer in Textile Systems, Part I," Textile Research Journal, 32:8, August, 1962, 628-633.

Woodcock, A. H. "Moisture Transfer in Textile Systems, Part II," Textile Research Journal, 32:9, September, 1962, 719-723.

Woodcock, A. H., Thwaites, H. L., and Breckenridge, J. R. "Clothed Man," Mechanical Engineering, 81:8, August, 1959, 71-74.

Other Sources

Anon. Institute for Environmental Research. Manhattan: Kansas State University, n.d.

Arkansas Technical Service Bulletin. Cooliecloth. Newark, N.J.: Arkansas Company Incorporated, n.d.

Booker, Gaylon B. Cotton in the Knitting Industry. Memphis, Tenn.: Market Research Service, National Cotton Council of America, June, 1968.

Cotton Incorporated. What Consumers Think about Today's Fibers and Fabrics. New York: Cotton Incorporated, n.d.

DuPont Industrial Chemicals Information Bulletin. Zelcon "TGF" Antigraying Agent. Wilmington, Dela.: E. I. DuPont de Nemours and Co., n.d.

Eastman Kodak. A Study of the Comfort of Knit Underwear Containing Kodel Polyester Fiber. Publication No. TB-K-172. Kingsport, Tenn.: Eastman Kodak, n.d.

Hollies, N. R. S., and Penoyer, John A. Clothing Hygrometer. USP 3,550,439, September 30, 1968.

Unpublished Works

Engle, Damon L. "The Internal Pore Structure of Polyvinyl Chloride Resins." Paper presented before the Philadelphia Section of the Society of Plastics Engineers, October 22, 1963.

Faris, B. F., Technical Services Director, E. I. DuPont de Nemours, Inc., Dacron Dyeing and Finishing, Wilmington, Dela. Correspondence, September 18, 1974.

Greenberg, Samuel, Product Manager, American Instrument Co., Silver Spring, Md. Correspondence, October 21, 1974.

Harper, Robert J., Jr., Research Leader-Pilot Plant Processes Research, Cotton Textile Chemistry Laboratory, USDA Agricultural Research Services, Southern Regional Research Center, New Orleans, La. Correspondence, September 19, 1974, plus two unpublished papers: "Experimental Data and Text Procedures" and "Fabric Preparation and Preparation for Testing."

Knight, Billy Arnold. "The Effect of Cotton and Synthetic Fiber Blends on the Moisture Responses of Basic Knit Structures." Unpublished Master's thesis, North Carolina State University, Raleigh, 1969.

Kremen, Jerome, Lagarias, John S., and Deitz, Victor R. "A New Approach to Surface Area Determinations: Selective Gas Adsorption in a Nitrogen-Helium System." Paper No. 110 delivered at Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, March 1-5, 1965.

Lauterback, H. G., and Kolb, H. J. "Wettability of Fibers." Paper presented before the Fiber Society, 1953.

Secondary Sources

Champaneria, A. J., and Lindbeck, M. R. (E. I. DuPont de Nemours and Co., BP 1,292,388, October 11, 1972.) Hollow Filaments, as abstracted in World Textile Abstracts, 4:21, November 15, 1972, Abstract No. 1498P.

Haase, J. "Theoretical Considerations on the Clothing/Hygiene Importance of Hygroscopicity of Fibres," Faserforschung un Textiltechnik Zeitschrift fur Polymerforschung (German), 25:4, 1974, 165-167, as abstracted in World Textile Abstracts, 6:16, August 31, 1974, Abstract No. 6212.

Kokoshinskaya, V. I., and Yakovleva, L. A. "Vapour-Permeability of Fabrics Containing Various Proportions of Synthetic Fibre," Tekhnologiya Tekstil'noi Promyshlennosti (Russian), No. 2(75), 1971, 25-28, as abstracted in World Textile Abstracts, 3:3, February 15, 1971, Abstract No. 766.

Marumo, H. Surface Modifier for Synthetic High Polymers, as abstracted in World Textile Abstract, 6:13, July 15, 1974, Abstract No. 4359P.

Mecheels, J., Demeler, R., and Muller, S. "Clothing Physiological Function of Double-layer Textiles," Melliand Textilberichte International (German), 54:12, 1973, 1356-1364, as abstracted in World Textile Abstracts, 6:3, February 15, 1974, Abstract No. 1031.

Miglyachenko, A. F., Orlov, I. V., and Onishchenko, V. F. "Effect of Temperature on Water Vapour Permeation Through Fabric and Changes in Its Moisture Content," Tekhnologiya Legkoi Promyshlennosti (Russian), No. 2(98), 1974, 25-27, as abstracted in World Textile Abstracts, 6:17, September 16, 1974, Abstract No. 6802.

Miglyachenko, A. F., Patsova, L., and Poltaveta, N. V. M. "Water Retaining Properties of Fabrics," Legkaya Promyshlennost Kazakhstana (Russian), No. 4, 1970, 13-16, as abstracted in Chemical Abstracts, 73:12, September 21, 1970, Abstract No. 57009w.

Mitsubishi Rayon Co., Ltd. Hygroscopic Acrylic Fibres and a Process for Producing the Same, BP 1,345,266, January 30, 1974, as abstracted in World Textile Abstracts, 6:4, February 28, 1974, Abstract No. 2261.

Mitu, S. "Moisture Absorption by Clothing," Industria Textila (Roumanian), 23:1, 1972, 28-33, as abstracted in World Textile Abstracts, 4:6, March 31, 1972, Abstract No. 2345.

Muller, S., and Hafer, M. "Foam-Cushion Method for the Determinations of the Moisture Transport in Wearing Apparel," Textiltechnik (German), 23:9, 1973, 580-590, as abstracted in World Textile Abstracts, 5:24, December 31, 1973, Abstract No. 10181.

Nan-Nichi, T., Kanazumi, E., Osugi, I., and Iwao, C. "Study of the Wearing Comfort of Apparel under Dynamic Conditions: II, The Shape of the Sleeve with Regard to the Pressure of Clothing around the Armhole," Journal of the Japan Research Association for Textile End-Uses (Japanese), 13:5, 1972, 178-183, as abstracted in World Textile Abstracts, 6:16, August 31, 1974, Abstract No. 6213.

Nawrocki, A. "Effect of Some Parameters of the Structure of Yarn and Knitted Fabric on Air and Water-Vapour Permeability and Perspiration Transmission of the Fabric," Prace Instytutu Wlokiennictwa (Polish), 21, 1971, 83-117, as abstracted in World Textile Abstracts, 4:10, May 31, 1972, Abstract No. 4208.

Nesswetha, W. "Comparative Studies on Sheets and Bedding of Natural and Synthetic Fibres," Melliand Textilberichte International (German), 63:10, 1972, 1174-1180, as abstracted in World Textile Abstracts, 4:21, November 15, 1972, Abstract No. 8581.

Orlov, I. V., Dovgosheya, S. T., Lutsyk, V. T., and Lutsyk, R. V. "Complex Investigation of the Macroporous Structure of Fabrics: II, Investigation of the Macroporous Structure of Fabrics by Several Independent Methods," Teknologiya Legkoi Promyshlennosti (Russian), No. 2(98), 1974, 40-44, as abstracted in World Textile Abstracts, 6:17, September 16, 1974, Abstract No. 6800.

Raducanu, I. "Physico-Mechanical and Comfort Properties of Some Warp Knits," *Industria Textila* (Roumanian), 22:2, 1971, 91-97, as abstracted in *World Textile Abstracts*, 4:10, May 31, 1972, Abstract No. 4213.

Suzuki, Atsushi, and Ohira, Michiyasu. "Measurement of Moisture Transfer Through Fabrics by Means of Humidity-Gradient Method," *Sen-i Gakkaishi* (Japanese), 26:3, 1970, 109-116, as abstracted in *Chemical Abstracts*, 73:6, August 10, 1970, Abstract No. 26453g.

Teijin, Ltd., and Moriga, H. *Fibrous Materials with Hydrophilic and Antistatic Properties and Improved Method for Production Using the Same*, USP 3,563,794, February 16, 1971, as abstracted in *World Textile Abstracts*, 3:8, April 30, 1971, Abstract No. 2473P.

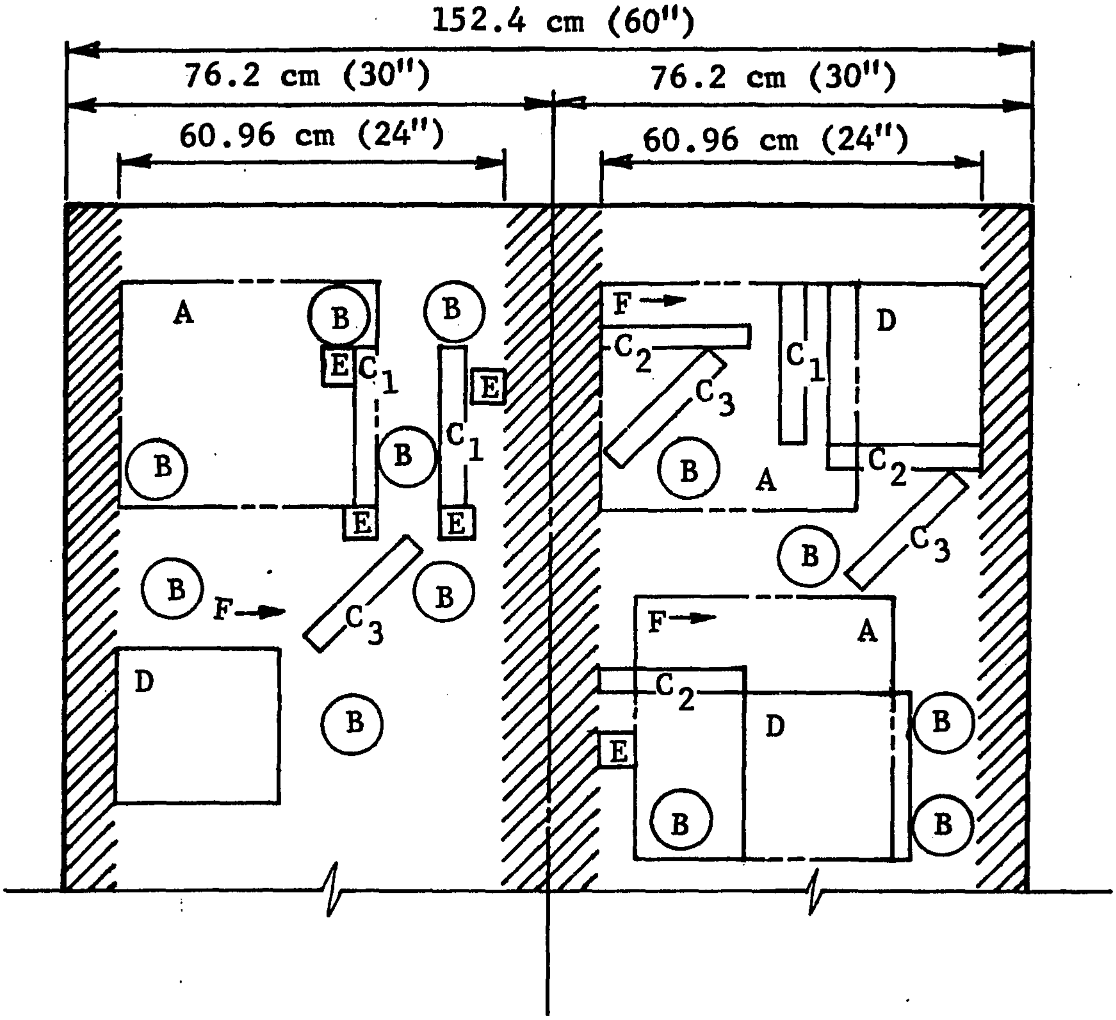
Thackray, Wendy D. (Imperial Chemical Industries, Ltd.). *Poly (Ethylene Terephthalate) Fibers of Increased Moisture Absorption*, as abstracted in *Chemical Abstracts*, 77:4, July 24, 1972, Abstract No. 21447f.

Voinov, Yu. F., and Karlina, K. V. "Assessment of the Thermal Resistance of Clothing," *Tekhnologiya Legkio Promyshlennosti* (Russian), 1:85, 1972, 80-84, as abstracted in *World Textile Abstracts*, 4:12, June 30, 1972, Abstract No. 4928.

Widder, A. G. R., Distler, H., and Fuchs, F. (Badische Anilin and Soda Fabrik). *Method of Rendering Textile Materials Absorptive*, USP 3,672,978, June 27, 1972, as abstracted in *World Textile Abstracts*, 4:15, August 15, 1972, Abstract No. 6026P.

APPENDIX A

DIAGRAM OF SAMPLING PLAN



APPENDIX A

Fig. 9. Diagram of Sampling Plan*

A --Dimensional Stability
B --Moisture Transport
C_1--Vertical Wicking
C_2--Horizontal Wicking
C_3--Bias Wicking
D --Air Permeability
E --Basic Fabric Properties
F --Yarn Construction

*See following page for complete information.

Fig. 9--continued

Code	Test	No. of Specimens	Specimen Size S.I. (U.S.)
A	Dimensional Stability (also wale count)	3	45.72 x 45.72 cm (18" x 18")
B*	Moisture Transport	12	11 cm (4.3") diameter
C	Wicking C1 = Warp C2 = Filling C3 = Bias	3	25.5 cm x 3 cm (10" x 1 1/5")
D	Air Permeability	3	25.4 x 25.4 cm (10" x 10")
E	Basic Fabric Properties: Thickness, Weight, % Moisture Regain, % Saturation Regain, % Moisture Imbibition after Centrifugation	5	5.1 cm x 5.1 cm (2" x 2")
F	Yarn Construction--Fiber Length, Yarn Twist, and Yarn Number; yarns unraveled from areas marked.		

*Six of the specimens used for vapor transport were later used for drop absorption.

APPENDIX B

FABRIC AND TEST SEQUENCES

FABRIC AND TEST SEQUENCES

The testing sequences were randomly selected by use of a card draw. Due to the time required to perform the moisture transport test series, other basic fabric property tests were performed in random sequence during this time.

Sequence for Performance of Tests

Moisture Transport Test Series.

(Moisture Form/Air Currents)

1. Vapor form/moderate currents
2. Liquid form/moderate currents
3. Liquid form/ambient air
4. Vapor form/ambient air

Basic Fabric Property Tests.

1. Yarn designation
2. Vertical wicking--filling, warp, bias
3. Evaluation of wettability
4. Air permeability
5. The following tests were performed in succession; the same five basic specimens were used for each test. There was no problem with contamination. The sequence for this group of tests was randomly selected; however, the sequence for the test could not be randomly selected. The sequence was as follows:
    - a. Fabric thickness
    - b. Fabric weight

c. Percent moisture regain

d. Percent saturation regain

e. Percent moisture retained after centrifugation

Sequence for Testing Fabrics.

	Fiber Content	Fabric Structure
1.	100% polyester	Interlock
2.	100% cotton	Interlock
3.	Control* (when applicable)	Control
4.	50/50% cotton/polyester	Jersey
5.	100% polyester	Jersey
6.	100% cotton	Jersey
7.	50/50% cotton/polyester	Interlock

---

*A control was used only in the moisture transport test series. The control was test using no fabric specimen over the moisture test area.

APPENDIX C

DESIGNATION OF YARN CONSTRUCTION

Table 57

Designation of Yarn Construction

YARN DESIGNATION FOR SPUN YARNS (BY S.I. UNITS)*

Fabric Structure	Fiber Content	Yarn No.	System	Direction of Twist	Amount Twist	(Fiber, Length, Type)
Interlock	C	17	tex	Z	4.3 t.p.cm.	(C, 20mm, staple)
Interlock	C/P	17	tex	Z	5.7 t.p.cm.	(50/50% C/P, 25mm, staple)
Jersey	C/P	32	tex	Z	5.7 t.p.cm.	(50/50% C/P, 25mm, staple)
Jersey	C	36	tex	Z	3.8 t.p.cm.	(C, 25mm, staple)
YARN DESIGNATION FOR SPUN YARNS (BY U.S. CUSTOMARY UNITS)						
Interlock	C	151	denier	Z	11 t.p.i.	(C, 78", staple)
Interlock	C/P	152	denier	Z	14 t.p.i.	(C/P, 98", staple)
Jersey	C/P	291	denier	Z	14 t.p.i.	(C/P, 98", staple)
Jersey	C	322	denier	Z	10 t.p.i.	(C, 98", staple)

---

*Designation of Yarn Construction, ASTM D1244--6. Designation of Single Yarns.

CODE: C = 100% cotton; C/P = 50/50% cotton/polyester; P = 100% polyester.
t.p.cm. = twists per centimeter; t.p.i. = twists per inch.

Table 57--continued

YARN DESIGNATION FOR FILAMENT YARNS (BY S.I. UNITS)***

Fabric Structure	Fiber Content	Textured**	Yarn No.	System	Filament	No. of Filaments/ Yarn	Twist (fiber)
Jersey	P	B	17	tex	f	34	t^0 (P)
Interlock	P	B	17	tex	f	40	t^0 (P)
YARN DESIGNATION FOR FILAMENT YARNS (BY U.S. CUSTOMARY UNITS)							
Jersey	P	B	150	denier	f	34	t^0 (P)
Interlock	P	B	150	denier	f	40	t^0 (P)

**6.1 spun single yarns.

***6.3 and 6.3.3--filament and bulked single yarns; B = bulked; f = filament; t^0 = zero twist.

CODE: P = 100% polyester.

APPENDIX D

WALES PER UNIT AREA

Table 58

Wales per Unit Area*

Fiber Content	Fabric Structure	W.P.Cm.**		S.P.I.***	
		Before Scour	After Scour	Before Scour	After Scour
C	Jersey	10.23	11.02	26	28
C	Interlock	14.57	15.35	37	39
C/P	Jersey	10.63	11.02	27	28
C/P	Interlock	14.57	15.75	37	40
P	Jersey	13.39	13.78	34	35
P	Interlock	13.78	14.57	35	37

*ASTM D231, Standard Methods of Testing and Tolerances for Knit Goods.

**S.I. units--wales per centimeter (W.P.Cm.)--values not rounded because they become less accurate.

***U.S. Customary Units--wales per inch (W.P.I.)--larger number therefore rounded to largest whole number--instrument gauge reads in inches, then converted to S.I. units.

CODE: C = 100% cotton; C/P = 50/50% cotton/polyester;
P = 100% polyester.

APPENDIX E

DIMENSIONAL CHANGES--FABRIC SHRINKAGE

Table 59

Dimensional Changes--Fabric Shrinkage*

Fiber Content	Fabric Structure	Warp Direction	Weft Direction
C	Jersey	4%	5%
	Interlock	3%	3%
C/P	Jersey	3%	3%
	Interlock	2%	1%
P	Jersey	2%	2%
	Interlock	2%	2%

*Tests and calculations performed according to ASTM D1777-64.

CODE: C = 100% cotton; C/P = 50/50% cotton/polyester;
P = 100% polyester.

APPENDIX F

F TABLE VALUES

Table 60

F Table Values

df Denominator/ df Numerator	F Values Level of Significance .01**	.05*
1/40	12.61	8.83
1/60	11.97	8.49
2/40	8.25 7.76	6.07 5.8

**.01--highly significant.

*.05--significant

SOURCE: B. J. Winer, Statistical Principles in Experimental Design (2nd ed.; New York: McGraw-Hill Book Co., 1971), Table C.3, F Distribution, pp. 864-868.

The value needed was x/48; however, the table showed only x/40 and x/60. The x/40 requires a larger number for significance. It was not necessary to interpolate, since all variables which were significant met the more severe x/40 table values. Those variables which were not statistically significant did not meet the lower x/60 table values.

APPENDIX G

NEWMAN-KEULS' POST-HOC ANALYSIS FOR FIBER CONTENT FROM THE MOISTURE TRANSPORT TEST SERIES

Table 61

Newman-Keuls' Post-Hoc Analysis for Fiber Content from the Moisture Transport Test Series

Calculations:

		Rank 3	2	
A	Q .99 (r,f) Q .95 (r,f) r=rank f=d.f.=2	19.0 8.5	14.0 6.09	Table Values--Distribution of the Studentized Range Statistic; Winer--Table C.4.
B	n MS_{error}	.00789	.00789	
C	A x B .99 A x B .95	.14991 .06707	.11046 .04805	

Test on Fiber Content Levels:

	C	P	C/P	4	N-K	
Means	.06846	.14467	.17567		.99	.95
C .06846		.07621*	.10721*	3	.14991	.06707
P .14467			.03100	2	.11046	.04805
C/P .17567						

Conclusions:

Fiber Content	Transport Rate (g/m^2/24 hrs x 10^{-2})
C ≠ P	6.846 ≠ 14.467
C ≠ C/P	6.846 ≠ 17.567
Therefore, C ≠ P ≠ C/P	6.846 ≠ 14.467 ≠ 17.567
P = C/P	14.467 = 17.567

**.01 level of significance--highly significant

*.05 level of significance--significant

SOURCE: B. J. Winer, Statistical Principles in Experimental Design (2nd ed.; New York: McGraw-Hill Book Co., 1971).

APPENDIX H

SPEARMAN RHO CORRELATION COEFFICIENT TABLE VALUES

Table 62

Spearman Rho Correlation Coefficient Table Values

.20⁺⁺	.10⁺	.05*	.02**	.01***
.66	.83	.89	.94	1

***Perfect correlation for this, 1 = perfect correlation.

**Highly significant.

*Significant.

++Trend, .10.

+Weak trend, .20.

SOURCE: Merle W. Tate and Richard C. Clelland, <u>Nonparametric and Shortcut Statistics</u> (Danville, Ill.: Interstate Printers and Publishers, Inc., 1957).